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AN AERIAL RADIOLOGICAL SURVEY OF THE OAK RIDGE RESERVATION AND SURROUNDING AREA

OAK RIDGE, TENNESSEE

DATE OF SURVEY: SEPTEMBER 1989

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This Document is UNCLASSIFIED

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ABSTRACT

An aerial radiological survey of the Oak Ridge Reservation (ORR) and surrounding area in Oak Ridge, Tennessee, was conducted from September 12-29, 1989. The purpose of the survey was to measure and document the site's terrestrial radiological environment for use in effective environmental management and emergency response planning. The aerial survey was flown at an altitude of 91 meters (300 feet) along a series of parallel lines 152 meters (500 feet) apart. The survey encompassed an area of 440 square kilometers (170 square miles) as defined by the Tennessee Valley Authority Map S-16A of the entire Oak Ridge Reservation and adjacent area.

The results of the aerial survey are reported as inferred exposure rates at 1 meter above ground level (AGL) in the form of a radiation contour map. Typical background exposure rates were found to vary from 5 to 14 microroentgens per hour (μR/h). The man-made radionuclides, cobalt-60, cesium-137, and protactinium-234m (a radioisotope indicative of depleted uranium), were detected at several facilities on the site. A comparison of the present radiological data with that from past aerial surveys is also presented.

In support of the aerial survey, ground-based exposure rate and soil sample measurements were obtained at several locations within the survey boundary. The exposure rate values obtained from the aerial and ground-based measurements were found to agree within $\pm$15%.

In addition to the large scale aerial survey, two special flyovers were requested by the Department of Energy. The first request was to conduct a survey of a 1-mile $\times$ 2-mile area in south Knoxville, Tennessee. The area had been used previously to store contaminated scrap metals from operations at the Oak Ridge site. The second request was to fly several passes over a 5-mile length of railroad tracks leading from the Oak Ridge Y-12 Plant, north through the city of Oak Ridge. The railroad tracks had been previously used in the transport of cesium-137.

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1.0 INTRODUCTION

The United States Department of Energy (DOE) maintains an aerial radiological surveillance capability called the Aerial Measuring System[1] (AMS). The AMS is based at the DOE Remote Sensing Laboratories located at Nellis Air Force Base in Las Vegas, Nevada, and Andrews Air Force Base in Washington, D.C. Since its inception in 1958 by the Atomic Energy Commission (predecessor to the DOE), the AMS has been used in a nationwide program to map the terrestrial gamma radiation environment in and around facilities producing, using, and/or storing radioactive materials. The AMS is presently operated and maintained by EG&G Energy Measurements (EG&G/EM), Inc., under contract to the DOE. The aerial surveys provide data for assisting in effective environmental management at nuclear facilities as well as providing radiological background templates for repeat surveys in the event of a large-scale radioactive release.

EG&G Energy Measurements routinely conducts aerial surveys for the Department of Energy, the Nuclear Regulatory Commission, and other government agencies as part of an ongoing nationwide program to map and document the radiological baseline conditions at various nuclear sites regulated by the United States government. Aerial radiological surveys have been effective in detecting areas which exhibit anomalous radiation levels, determining average ground level exposure rates, and identifying specific radionuclides associated with anomalous radiation areas.

The first aerial radiological survey of the Oak Ridge Reservation and surrounding area was conducted during the spring of 1959 by the United States Geological Survey (USGS) using a fixed-wing aircraft flying at a 500-foot altitude and one-mile line spacing.[2] Its primary purpose was to characterize the radiogeology of the area.

The next aerial survey[3] was conducted in 1973 by EG&G/EM using a fixed-wing aircraft flying at an altitude of 152 meters (500 feet) and a speed of 170 knots. Sites identified as having anomalous radiation levels were resurveyed with a helicopter-mounted AMS system flying at an altitude of 76 meters (250 feet) and a speed of 70 knots. The increased sensitivity achieved using the low-flying helicopter provided detailed coverage of the radiological activity at the anomalous radiation sites. In 1980, an aerial radiological survey[4] of the entire Oak Ridge Reservation and nearby surrounding area, encompassing 440 square kilometers (170 square miles), was conducted. The survey consisted of flying a series of parallel flight lines 152 meters (500 feet) apart at an altitude of 91 meters (300 feet). More recently, an aerial radiological survey[5] was completed over the White Oak Creek Floodplain (1986). In order to provide a detailed map of the terrestrial radiological environment, the survey was flown at an altitude of 46 meters (150 feet).

During September 12-29, 1989, an aerial radiological survey of the Oak Ridge Reservation, the city of Oak Ridge, and the surrounding area was conducted. The aerial survey was requested by the DOE to determine the extent of the radiological impact of the Oak Ridge Reservation operations on the surrounding environment over the last ten years. The parameters of the survey were chosen so they would be identical to those used during the 1980 survey to allow a direct comparison with previous results.

The survey encompassed an area of 440 square kilometers (170 square miles) which included the Oak Ridge National Laboratory, the Oak Ridge K-25 Site, the Oak Ridge Y-12 Production Plant, and the city of Oak Ridge. The purpose of the survey was to measure and document the site's terrestrial radiological environment for use in effective environmental management and emergency response planning. The radiation data is presented in the form of a template which, when superimposed on a Tennesee Valley Authority (TVA) S-16A (1987) map of the Oak Ridge Reservation, will give the gamma exposure rates at 1 meter above ground level (AGL) attributed to natural and man-made radionuclides.

In support of the aerial measurements, ground-based exposure rates and soil samples were obtained from four benchmark sites located within the survey boundary, but outside the Oak Ridge Reservation. Radionuclide assay of the soil samples was performed to determine radioisotopic concentrations. Oblique aerial photographs of the Oak Ridge facilities were also obtained in conjunction with the survey.

2.0 SURVEY SITE DESCRIPTION

The Oak Ridge Reservation, located in Oak Ridge, Tennessee, is operated for the DOE by Martin Marietta Energy Systems, Inc. The Oak Ridge Reservation consists of three major facilities: the Oak Ridge National Laboratory (ORNL), the K-25 Site (previously known as the Oak Ridge Gaseous Diffusion Plant), and the Y-12 Plant. The DOE owns approximately 150 square kilometers (58 square miles), bounded on the south and west by the Clinch River and to the north and east by a fence line as outlined on the TVA S-16A topographic map (Figure 1).

The ORNL operates several facilities which use, produce, and/or store nuclear materials. Most notable are several charged particle accelerators, the High Flux Isotope Reactor (HFIR), and the Health Physics Research Reactor (HPRR). The Tower Shielding Facility (TSF), also located at ORNL, is no longer in operation.

The K-25 Site, formally used to enrich uranium by the gaseous diffusion process, was placed on standby in 1985 and officially shut down in 1987. However, several thousand cylinders[6] of depleted uranium remain in outside storage, and the diffusion plant has not been decommissioned. The plant consists of a large industrial complex located in the northwest corner of the Oak Ridge Reservation, bordering the Clinch River to the east. Waste management activities and enrichment program support constitute the current mission of the K-25 Site.

The Oak Ridge Y-12 Plant has the primary mission to produce and fabricate nuclear weapons components. The Y-12 Plant also provides support to the Oak Ridge National Laboratory and other government agencies.

As a result of the multiplicity of operations using nuclear materials, man-made radioactive materials from past and current operations are present at various locations on the Oak Ridge Reservation.

3.0 NATURAL BACKGROUND RADIATION

Natural gamma radiation originates from radioactive nuclides which are present in minute concentrations in the earth and atmosphere as well as cosmic rays originating from outer space. Terrestrial radiation, which originates primarily from nuclides in the uranium decay chain, thorium decay chain, and radioactive potassium, is detected at the surface of the earth and has exposure rates between 1 and 15 μR/h (9 and 130 mrem/yr). The exposure rates from terrestrial radionuclides are dependent on the composition of the soil and bedrock near the

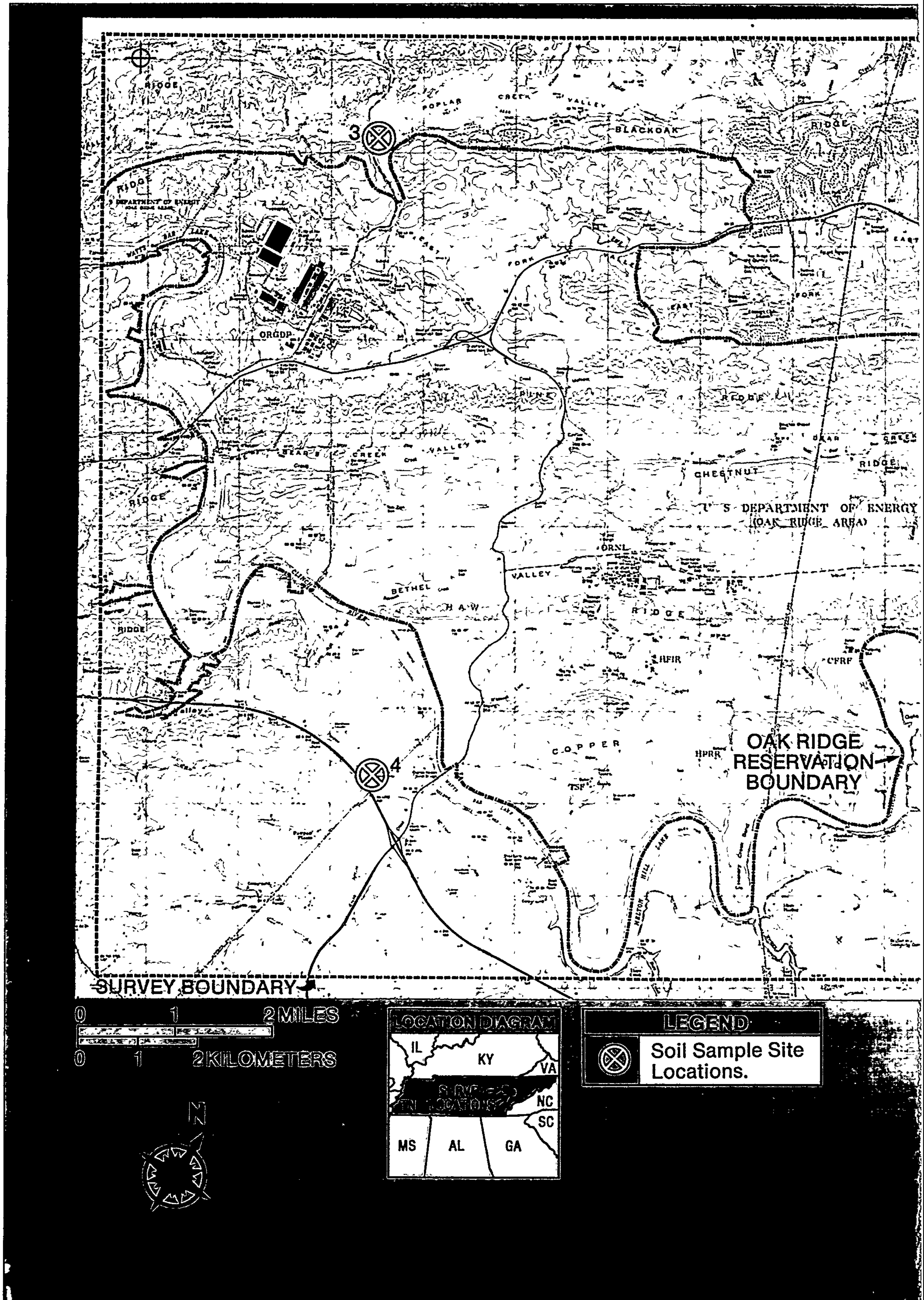
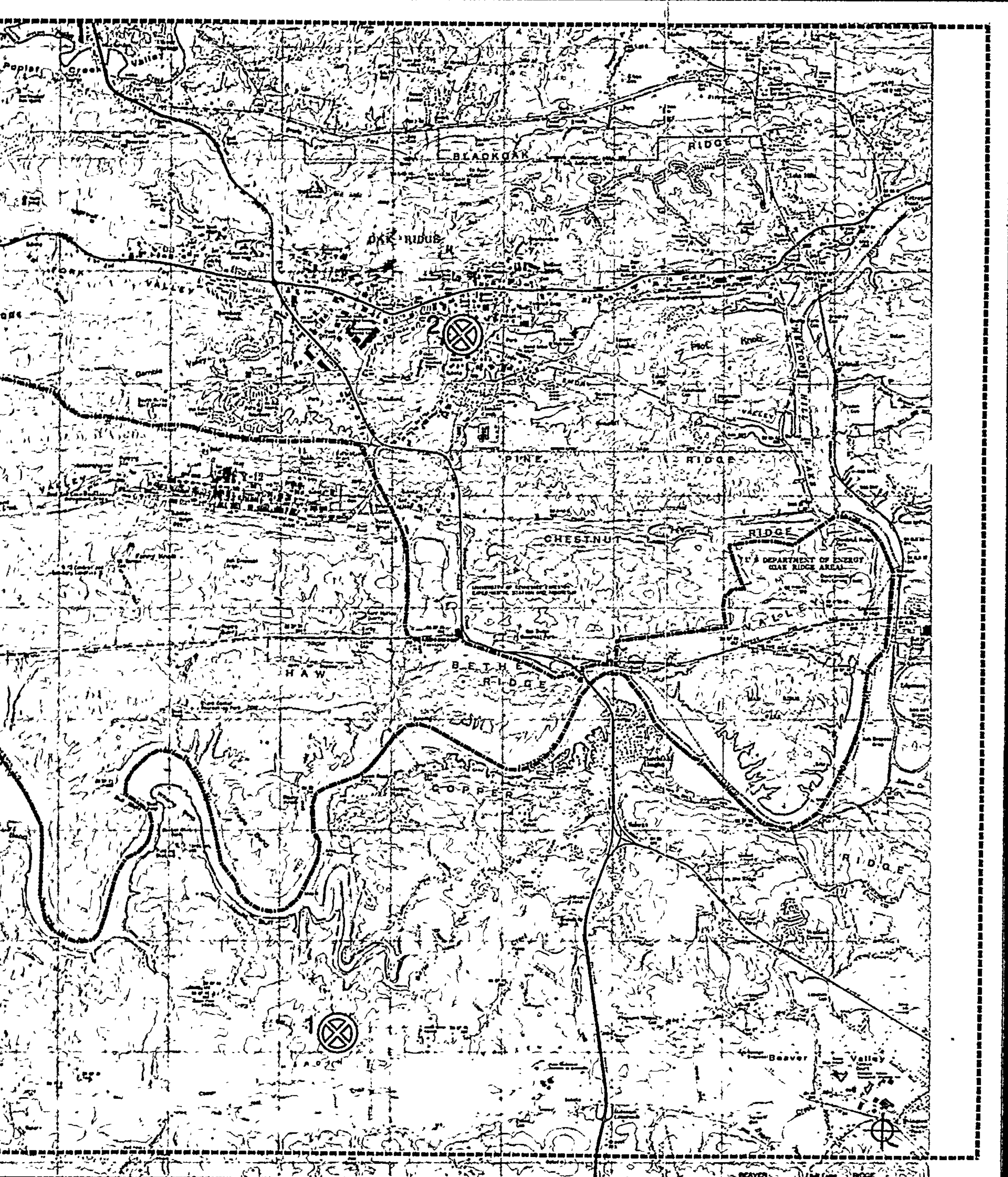


FIGURE 1. *TVA MAP S-16A OF T*



HE OAK RIDGE RESERVATION

point of interest. Cesium-137 (Cs-137), a by-product of nuclear fission, is also present in trace quantities worldwide as a result of fallout from above-ground nuclear weapons tests conducted prior to the early 1980s by the United States, the Soviet Union, and Great Britain and, subsequently, by China, India, and France. Exposure rates due to Cs-137 in the environment are typically less than 1 μR/h.[7]

Radon gas, a by-product in the decay chain of both uranium and thorium, diffuses through the soil into the atmosphere and contributes to the radiation levels near the surface of the earth. The radon concentration in a particular area, however, depends on several factors including meteorological conditions, mineral compositions, and soil permeability. Airborne radiation from radon and its decay products typically contribute from 1% to 10% to the natural radiation background.

Cosmic rays, high energy radiation originating from outer space, also contribute to the natural radiation background. The cosmic rays from outer space shower the earth with a nearly constant flux of radiation which interacts with atoms in the earth's atmosphere and soil producing an additional source of background activity. Radiation levels due to cosmic rays vary with altitude and geomagnetic latitude. Typical values range from 3.3 μR/h at sea level to 12 μR/h (up to 100 mrem/yr) at elevations of 3 kilometers (10,000 feet).[8] For the Oak Ridge area, the cosmic ray contribution is approximately 3.8 μR/h.

4.0 SURVEY EQUIPMENT AND PROCEDURES

4.1 Aerial Measuring System

The Oak Ridge survey was conducted using a Messerschmitt-Bolkow-Blohm BO-105 helicopter (Figure 2). The helicopter was outfitted with two large detector pods and a Radiation and Environmental Data Acquisition and Recorder System version IV (REDAR IV). The two large detector pods were mounted underneath the helicopter on the skid rack. Each pod contained four rectangular 5.1-cm × 10.2-cm × 40.6-cm (2-in × 4-in × 16-in) and one 5.1-cm × 10.2-cm × 10.2-cm (2-in × 4-in × 4-in) sodium iodide, NaI(Tl), gamma ray detectors. The energy response for the detector arrays was calibrated using gamma rays from americium-241 (Am-241) and sodium-22 (Na-22) radiation sources. At a survey altitude of 91 meters (300 feet), the large detector array will measure ground level distributed source exposure rates up to 75 μR/h. The two small detectors are used to extend the dynamic range of the aerial measuring system to approximately 1200 μR/h.

FIGURE 2. ***MBB BO-105 HELICOPTER WITH DETECTOR PODS***

Data acquisition was performed using the REDAR IV, a compact computer system designed for use in aircraft. The REDAR IV recorded and stored data on magnetic tape from the detector system and the aircraft positioning system as well as environmental variables such as ambient temperature and barometric pressure. The REDAR IV is also equipped with a multichannel spectrum analyzer and video display capabilities for in-flight monitoring of the gamma energy spectrum as well as other flight parameters.

The aircraft positioning was established using an ultra-high frequency (UHF) ranging system and the radar altimeter. Two ground-based transponders, one located at the DOE antenna site on Buffalo Mountain due north of the survey area and one positioned on a commercial communications tower located in Harriman, Tennessee, were periodically interrogated by a master unit in the helicopter. By the method of trilateration, the precision of the UHF ranging system is ±10 meters with an accuracy due to USGS map uncertainties of ±20 meters. The position information was recorded on magnetic tape and directed to a steering indicator to guide the aircraft along a predetermined set of flight lines.

4.2 Ground-Based Measurements

Total exposure rates and soil samples were obtained from four ground-based, benchmark sites for verification of the aerial measurements. The four sites (labeled 1-4 in Figure 1) were identified by the aerial survey as having only natural radioactivity. At each site, total exposure rates were measured using a gamma ionization chamber, and five soil samples were taken for laboratory analysis. Radionuclide assay of the soil samples was performed at EG&G/EM Santa Barbara Operations in accordance with previously outlined procedures.[9]

4.3 Mobile Data Processing Laboratory

The operations base for the survey was the Knoxville Downtown Island Airport in Knoxville, Tennessee, located about 24 kilometers (15 miles) due east of the Oak Ridge Reservation. The Radiation and Environmental Data Analyzer and Computer (REDAC) system (Figure 3) was located at the operations base. The REDAC system is a mobile computer laboratory for analysis of the aerial survey data recorded on the REDAR IV system. The mobile laboratory hosts a wide range of computer hardware which includes a Data General MV7800 XP computer with 4 megabytes of memory, a Winchester disk mass storage with 1.1 gigabytes for data storage, two 9-track tape drives for data transfer and archiving, a 36-inch wide plotter for data contouring, and three video graphics displays for data viewing. The REDAC system also houses an extensive library of software which was used to provide on-site preliminary analysis of the aerial data on a flight-by-flight basis as well as to monitor pre- and post-flight quality assurance checks for the AMS.

4.4 Survey Procedures

The aerial radiological survey of the Oak Ridge Reservation and surrounding area was conducted according to EG&G/EM standardized procedures[1,10] which will be discussed only briefly in this section.

FIGURE 3. ***MOBILE COMPUTER PROCESSING LABORATORY***

A series of measurements were conducted to determine the attenuation of gamma radiation as a function of altitude for use in the data analysis. The measurements consisted of altitude profiles flown over a large body of water and a designated land test line. An altitude profile consisted of a series of one-minute measurements over the water and test lines at altitudes ranging from 61 meters (200 feet) to 305 meters (1,000 feet). A section of the Clinch River was chosen for the water measurements. Data accumulated during the altitude profile over water were used to determine the nonterrestrial radiation; *i.e.*, radiation which originates from airborne radon, the helicopter and detector system, and cosmic rays.

For the land test line, an open field en route from the operations base to the survey area was chosen. The terrestrial radiation measured over the land test line, corrected for the nonterrestrial radiation measured over water, was used to derive the air attenuation coefficient for the gamma radiation. In addition, the test lines were flown at survey altitude during each flight; the water line was flown once each flight to monitor fluctuations in the radon concentrations, and the test line was flown at the beginning and end of each flight to verify the proper operation of the detection system.

The aerial survey covered an area of 440 square kilometers (170 square miles) as outlined in Figure 1. A grid pattern, consisting of 105 parallel flight lines separated by 152-meter (500-foot) intervals, was flown at an altitude of 91 meters (300 feet) AGL. All flights were flown at an average ground speed of 36 meters/second (70 knots).

5.0 DATA REDUCTION PROCEDURES

Two methods were used to analyze the aerial radiation data. The first was the gross count rate method which was used to determine ground level exposure rates. The second was the spectral window method which was used to determine the location of man-made radionuclides and to determine photopeak concentrations for specific radionuclides.

5.1 Gross Count Rate Method

The gross count rate is defined as the integrated count rate in the 38 to 3,026 keV energy window of a gamma energy spectrum. For natural background, the gross count rate consists primarily of gammas from potassium-40 (K-40), uranium-238 (U-238), thorium-232 (Th-232), and their decay products. The algorithm used to convert the gross count rate in counts per second (cps) measured at survey altitude to exposure rate in μR/h at 1 meter is:

$$\text{EXPOSURE RATE} = \frac{GC - BG}{693}\, e^{(A-300)C} \tag{1}$$

where

GC = gross count rate at survey altitude
BG = background count rate at survey altitude
A = survey altitude
C = air attenuation factor

The background count rate is comprised of gammas from the aircraft system, airborne radon, and cosmic rays. An air attenuation factor having a value of 0.0019/feet was deduced empirically from the altitude profile data. A conversion factor of 693 counts $\cdot$ sec^{-1} per μR $\cdot$ h^{-1} for 91 meters (300 feet) AGL was obtained from the documented[11] EG&G/EM calibration range near Washington, D.C. The applicability of the conversion factor assumes a uniformly distributed radiation source which covers an area which is large compared to the field of view of the detector system.

5.2 Man-Made Gross Count Rate Method

The aerial radiation data were also used to determine the location of man-made radionuclides. The man-made gross count (MMGC) is defined as the sum of the gross counts which are directly attributed to gammas from man-made radionuclides. In general, man-made radionuclides can be found from increases in the gross count rate. However, slight increases in the gross count rate are not considered adequate reason to suspect the presence of a man-made radionuclide. Moreover, slight variations in the gross count rate may be attributed to variations in the geologic structure or changes in the soil moisture content.

A more conclusive approach to detecting man-made radionuclides involves a comparison of the gross count rates from various spectral windows of the gamma energy spectrum. In particular, the ratio of the integrated count rates from different spectral windows of the gamma energy spectrum will remain nearly constant when only background radiation is present. Although this procedure can be applied to any region of the gamma spectrum, the most common practice is to place all counts below 1,394 keV (*i.e.*, the region of the gamma energy spectrum where most long-lived, man-made radionuclides emit radiation) into the source window and to place all counts above 1,394 keV (*i.e.*, the region of the gamma energy spectrum where primarily naturally occurring radionuclides emit gamma radiation) into the background window. The MMGC algorithm is sensitive to low levels of man-made radiation (*i.e.*, $<$1 μR/h) which would otherwise be masked by larger variations which often occur in natural background.

The MMGC rate can be expressed analytically in terms of the integrated count rates in specific spectral energy windows (in keV) from the gamma energy spectrum

$$\text{MMGC} = \sum_{E = 38\text{ keV}}^{1{,}394\text{ keV}} \text{counts}_E - K \sum_{E = 1{,}394\text{ keV}}^{3{,}026\text{ keV}} \text{counts}_E \tag{2}$$

where

$$\sum_{E = 38\text{ keV}}^{1{,}394\text{ keV}} = \text{integral count rate in the energy window from 38-1,394 keV}$$

$$\sum_{E = 1{,}394\text{ keV}}^{3{,}026\text{ keV}} = \text{integral count rate in the energy window from 1,394-3,026 keV}$$

and

$$K = \sum_{E = 38\text{ keV}}^{1{,}394\text{ keV}} \text{counts}_E \Bigg/ \sum_{E = 1{,}394\text{ keV}}^{3{,}026\text{ keV}} \text{counts}_E \tag{3}$$

The constant, K, was obtained from the summation spectrum composed of the gamma spectra acquired over a region of the survey area which was identified to contain only gamma radiation from naturally occurring radionuclides. The resultant MMGC obtained from the above algorithm will yield a nominal value equal to zero for areas containing only natural radionuclides and a value greater than zero for areas containing man-made radionuclides.

Since the MMGC algorithm is quite general and will respond to a wide range of radionuclides, the primary function of the MMGC is to locate man-made radioactivity. Once a region of man-made radioactivity has been located, a detailed analysis of the gamma energy spectrum is conducted to identify the radionuclides present. A more sensitive algorithm optimized for specific radionuclides can then be devised.

5.3 Photopeak Count Rate Method

Gamma energy spectra from regions of the survey area exhibiting man-made radioactivity were further analyzed to provide isotopic identification. The analysis of the gamma spectra primarily revealed the presence of three man-made radionuclides: cesium-137 (Cs-137), cobalt-60 (Co-60), and protactinium-234m (Pa-234m). Although Pa-234m occurs naturally in the environment as a decay product of uranium, its presence is only detected by the AMS when large quantities of uranium are concentrated.

Regions of the survey area which contained only Co-60, Pa-234m, Cs-137, and natural background were identified. Normalized background spectra were subtracted from spectra obtained in these areas to obtain a "pure" spectrum for each isotope. Appropriate energy windows from the isotope and background spectra were used to derive a set of linear equations. These equations extract individual isotope contributions from observed spectra which may contain any or all of the contributors. The calculated contributions are intended to cover the energy range 10% below through 10% above the photopeak(s) of interest to nominally match the detector resolution. Actual min./max. energies must be set at available hardware-determined values and may differ slightly from ±10% of the photopeak energy.

The following equations were used to extract the photopeak count rates (coefficient values shown may have been adjusted slightly on a flight-by-flight basis to compensate for changing conditions):

Co-60: Photopeak at 1,173 and 1,332 keV

Photopeak range from 1,046 to 1,466 KeV

$$\underset{\text{(photopeak)}}{\text{Co-60}} = 3.05\sum_{E = 1{,}250\text{ keV}}^{1{,}382\text{ keV}}\text{counts}_E - 0.662\sum_{E = 1{,}394\text{ keV}}^{3{,}026\text{ keV}}\text{counts}_E \tag{4}$$

Pa-234m: Photopeak at 1,001 keV

Photopeak range from 902 to 1,106 keV

$$\underset{\text{(photopeak)}}{\text{Pa-234m}} = 1.13\sum_{E = 902\text{ keV}}^{1{,}020\text{ keV}}\text{counts}_E - 1.81\sum_{E = 1{,}250\text{ keV}}^{1{,}382\text{ keV}}\text{counts}_E - 0.242\sum_{E = 1{,}394\text{ keV}}^{3{,}026\text{ keV}}\text{counts}_E \tag{5}$$

Cs-137: Photopeak at 662 keV

Photopeak range from 590 to 734 keV

$$\underset{\text{(photopeak)}}{\text{Cs-137}} = 1.10\sum_{E = 590\text{ keV}}^{722\text{ keV}}\text{counts}_E - 1.47\sum_{E = 902\text{ keV}}^{1{,}020\text{ keV}}\text{counts}_E - 2.95\sum_{E = 1{,}250\text{ keV}}^{1{,}382\text{ keV}}\text{counts}_E + 0.308\sum_{E = 1{,}394\text{ keV}}^{3{,}026\text{ keV}}\text{counts}_E \tag{6}$$

The photopeak count rates may be used to infer isotope activity on or in the soil. A computation, using a basic gamma transport model and measured detector response, was used to derive conversion factors that relate count rates of specific sources to activity. Table 1 lists conversion factors for possible distributions and minimum detectable activities (MDAs) of sources detected during the ORR survey.

Table 1. Count Rate to Activity Conversion Factors and Minimum Detectable Activity

Distributions	Photopeak Count Rate Conversion Factors - Cs-137				Minimum Detectable Activity			
Inverse Relaxation Depth, α (cm^{-1})	Distributed Source			Point Source	Distributed Source			Point Source
	μCi/m²/cps	pCi/gm/cps	pCi/gm/cps (5 cm sample)	mCi/cps	μCi/m²	pCi/gm	pCi/gm (5 cm sample)	mCi
Surface $\alpha = \infty$	0.0017			.052	0.014			4.10
10 $\alpha = .10$	0.0046	0.031	0.024		0.37	2.5	1.9	
Uniform $\alpha = 0$	0.285	0.019	0.019		2.3	1.5	1.5	

Distributions	Photopeak Count Rate to Activity Co-60				Minimum Detectable Activity			
Inverse Relaxation Depth, α (cm^{-1})	Distributed Source			Point Source	Distributed Source			Point Source
	μCi/m²/cps	pCi/gm/cps	pCi/gm/cps (5 cm sample)	mCi/cps	μCi/m²	pCi/gm	pCi/gm (5 cm sample)	mCi
Surface $\alpha = \infty$	0.0008			0.31	0.12			4.6
10 $\alpha = .10$	0.0020	0.013	0.0105		0.30	2.0	1.6	
Uniform $\alpha = 0$	0.11	0.0074	0.0074		16.73	1.1	1.1	

Distributions	Photopeak Count Rate to Activity Pa-234m				Minimum Detectable Activity			
Inverse Relaxation Depth, α (cm^{-1})	Distributed Source			Point Source	Distributed Source			Point Source
	μCi/m²/cps	pCi/gm/cps	pCi/gm/cps (5 cm sample)	mCi/cps	μCi/m²	pCi/gm	pCi/gm (5 cm sample)	mCi
Surface $\alpha = \infty$	0.26			9.0	18			630
10 $\alpha = .10$	0.65	4.3	3.4		45	303	239	
Uniform $\alpha = 0$	38	2.5	2.3		2,600	180	180	

Activity distributions are assumed to be uniform in the horizontal direction. The vertical distribution is evaluated assuming the exponential case:

$$A = A_0 e^{-\alpha z} \tag{7}$$

where

A = the activity
A_0 = the activity at the soil surface
$\not\equiv$ = the exponential distribution parameter
z = the depth in the soil

All conversion factors relate a specific spectral photopeak count rate to the activity on the soil surface or at a specific depth in the soil. The surface and uniform volume distributions can be estimated by assigning the depth distribution parameter values of 0 and ∞ respectively. Activities of different distributions usually fall between the uniform and surface cases.

The minimum detectable activity (MDA) of each source listed in Table 1 is a product of the conversion factor and a multiple of the uncertainty ($n\sigma$). The $n\sigma$ factor was chosen so that perturbations are eliminated in areas of naturally occurring radiation. Sigma (σ) is the computed standard deviation of the net algorithm results. The level of uncertainty is defined as the lowest count rate contour interval. For Cs-137, Co-60, and Pa-234m, the levels of uncertainty are 80 cps (5σ), 150 cps (9σ), and 70 cps (7σ) respectively.

6.0 RESULTS

6.1 Terrestrial Exposure Rate Contour Map

The terrestrial exposure rates were deduced from over 90,000 measurements, integrated with the corresponding aircraft position coordinates, and compiled to produce a three-dimensional contour map or template. Figure 4 is the exposure rate contour map superimposed on the TVA Map S-16A of the Oak Ridge Reservation showing the exposure rates (μR/h) for 1 meter AGL inferred from the aerial data. Included in the radiation data is an estimated cosmic ray exposure rate of 3.8 μR/h.[8] The exposure rates are attributed to natural radionuclides in the soil, man-made radiation sources, and cosmic rays.

6.2 Man-Made Gross Count Rate Contour Map

Figure 5 shows the man-made gross count contour map superimposed on the TVA Map S-16A of the Oak Ridge Reservation. The contour map shows the locations of man-made radiation sources detected within the survey boundary. The magnitude of the count rate provides an indicator of the relative intensities for the radiation sources. It is nearly impossible to convert man-made gross count rates to activity levels or exposure rate due to the complex mixture of radionuclides involved. A total of 26 man-made radiation sources were identified within the survey boundary and are labelled as Regions of Interest (ROIs) in Figure 5.

6.3 Photopeak Count Rate Contour Map

Figures 6, 7, and 8 present the photopeak contour maps for Co-60, Pa-234m, and Cs-137, respectively, superimposed on the TVA map of the Oak Ridge Reservation. The contour maps show the photopeak count rates measured at survey altitude.

6.4 Gamma Spectra

Figure 9 shows a typical gamma energy spectrum of the background radioactivity in the Oak Ridge area. The radioisotopes identified are those from naturally occurring U-238, Th-232, K-40, and their decay products.

Figures 10-35 are the net gamma spectra for the 26 anomalous radiation ROIs denoted in Figure 5. The net gamma spectra are used to identify the radionuclides which contribute to the anomalous radiation levels. A net gamma energy spectrum is generated by normalizing the source and background spectra to the integral count rate in the 1,394-3,026 keV spectral window and then subtracting the background spectrum. The primary radionuclides identified from the net gamma spectra were Co-60, Pa-234m, and Cs-137.

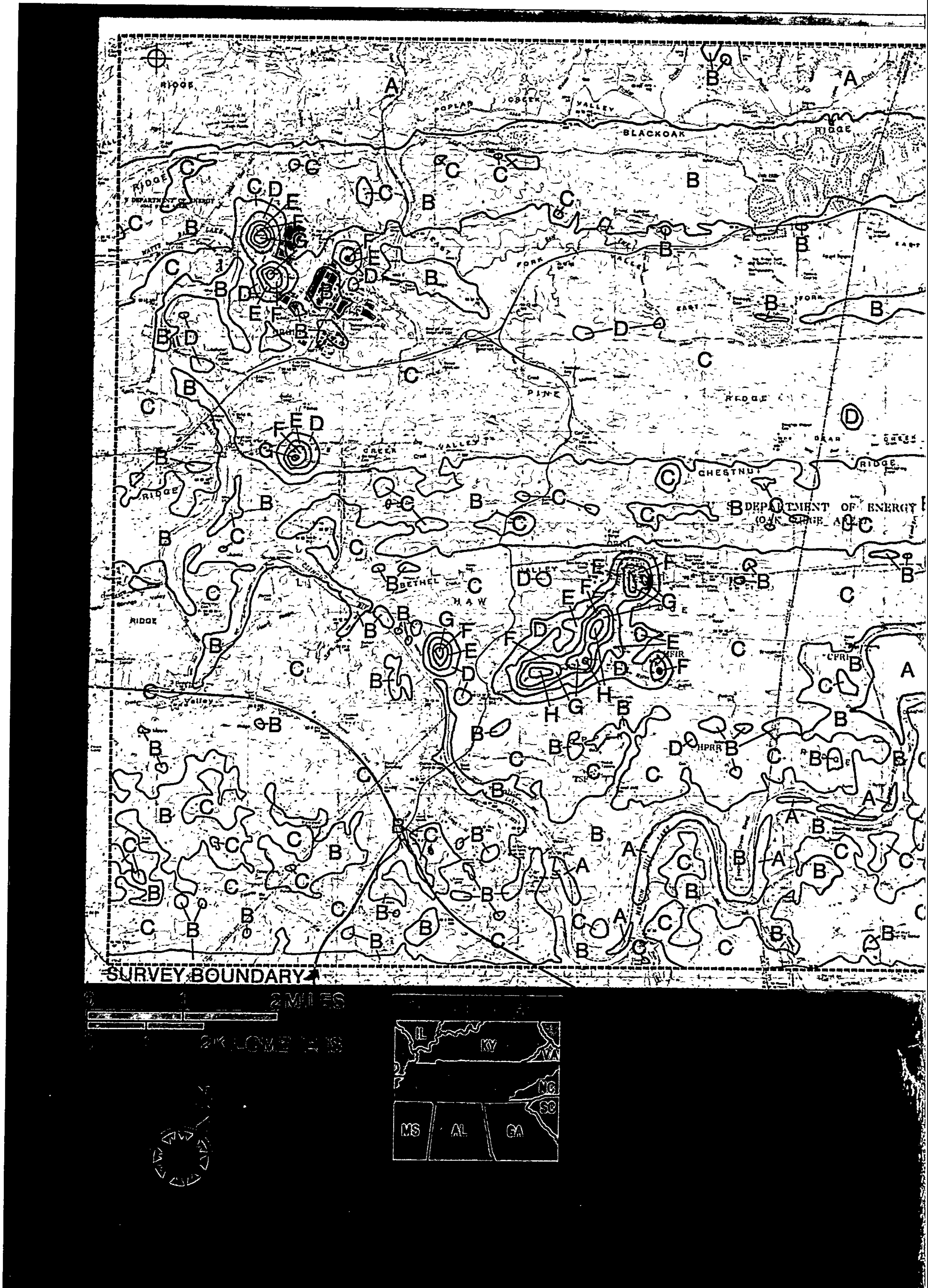
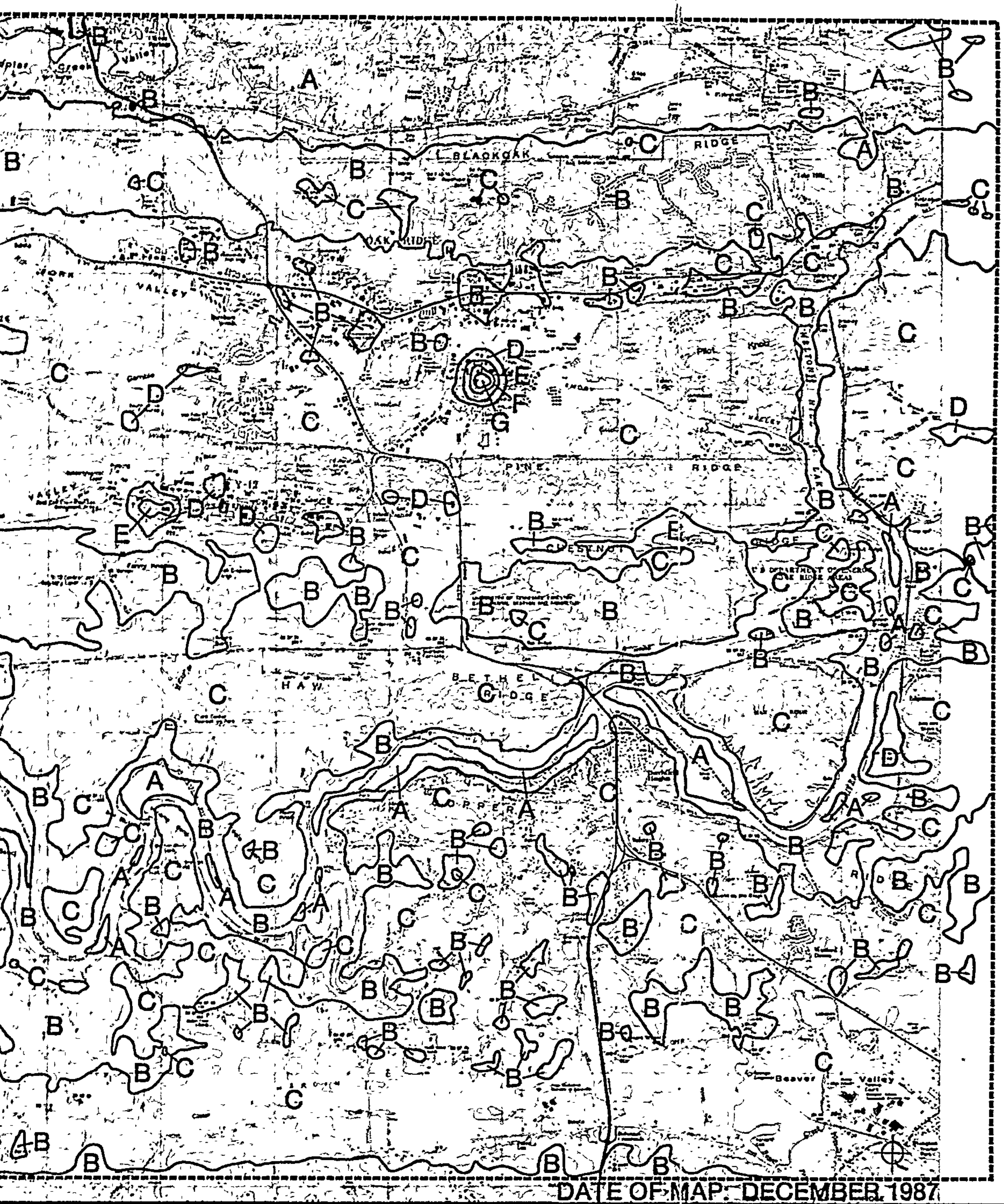


FIGURE 4. *TERRESTRIAL GAMMA E*



*Terrestrial external exposure rates are inferred from aerial data collected at 91 meters (300 ft AGL). Includes a cosmic ray exposure rate of 3.8 μR/h.

LETTER LABEL	TERRESTRIAL EXTERNAL EXPOSURE RATE AT 1 METER μR/h*
A	< 5
B	5 - 8
C	8 - 14
D	14 - 35
E	35 - 80
F	80 - 200
G	200 - 600
H	600 - 1,500

XPOSURE RATE CONTOUR MAP

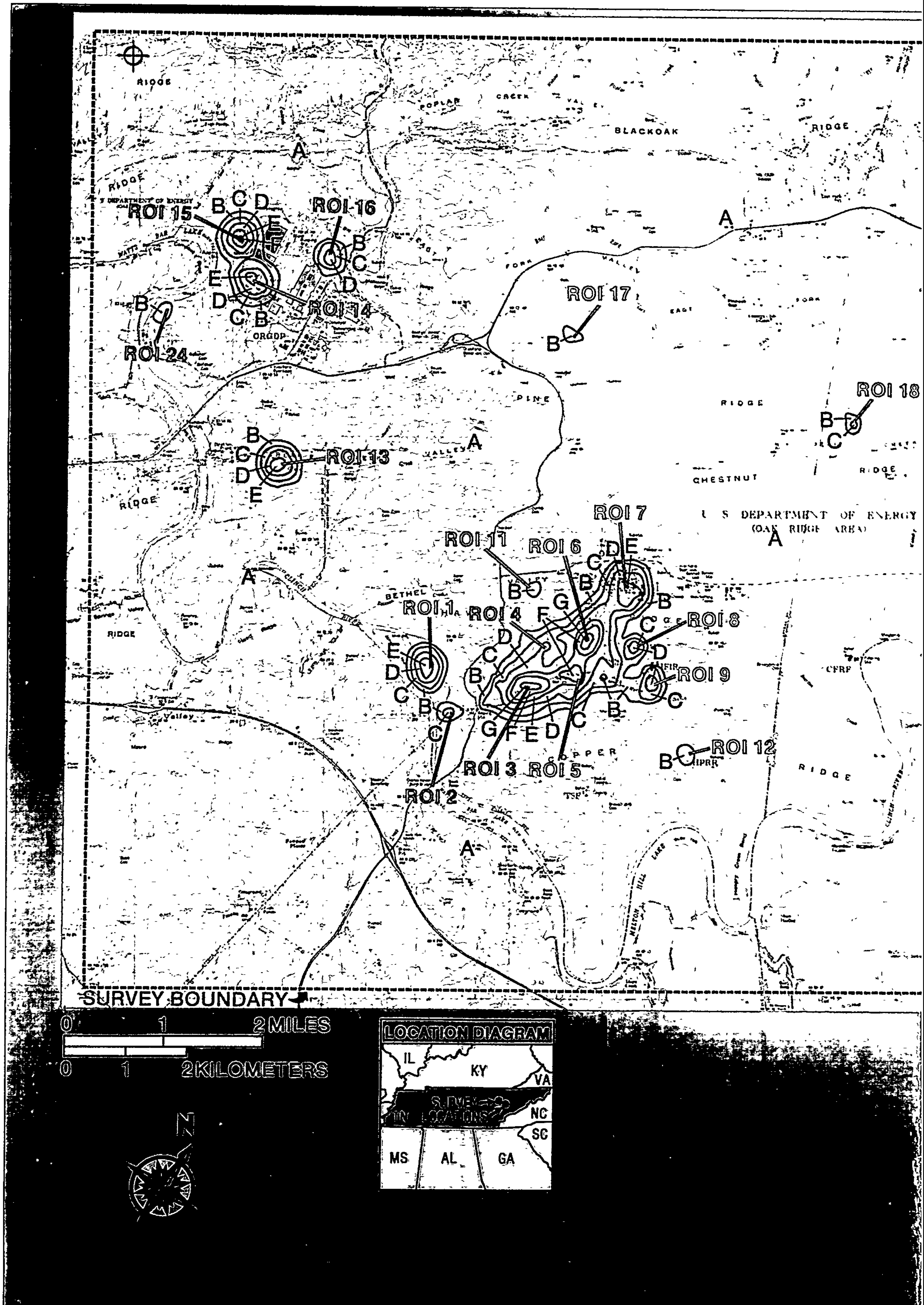
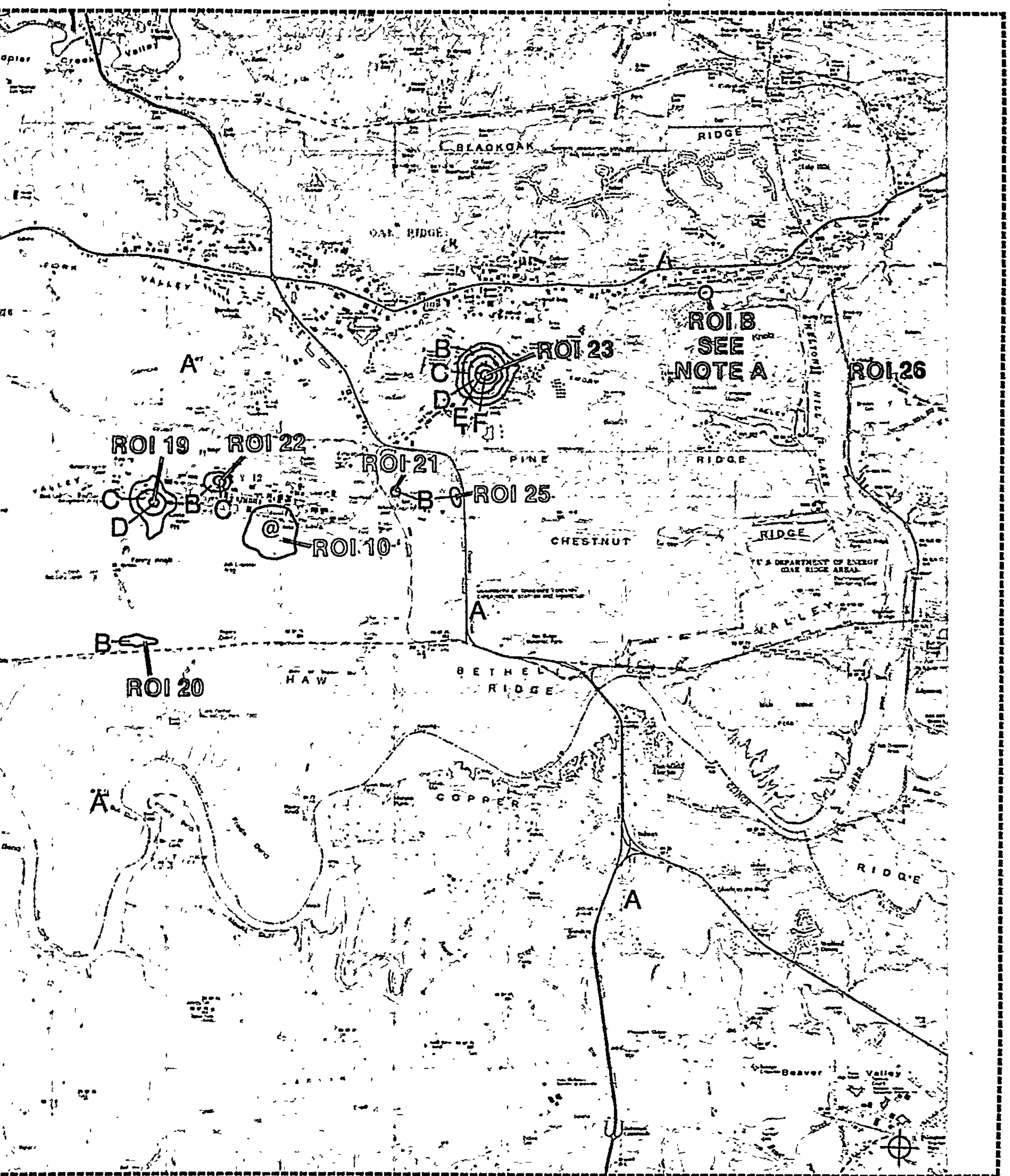


FIGURE 5. *MAN-MADE GROSS*



DATE OF MAP: DECEMBER 1987

The data shown have been processed in a manner that suppresses the natural background. The results are displayed as relative levels of man-made radionuclide activity. It is nearly impossible to convert the relative levels of activity to a meaningful exposure rate because of the complex mixture of the nuclides.

*At flight altitude of 91 m (300 ft) eight 2″ × 4″ × 16″ NaI(Tl) gamma detectors

NOTE A

Cesium-137 was detected at this location during the special flight over the railroad track. This location was not detected during the primary survey.

MAN-MADE GROSS COUNT CONVERSION SCALE

LETTER LABEL	COUNTS PER SECOND*
@	< 0
A	0 – 2,000
B	2,000 – 6,000
C	6,000 – 20,000
D	20,000 – 70,000
E	70,000 – 180,000
F	180,000 – 500,000
G	500,000 – 1,500,000

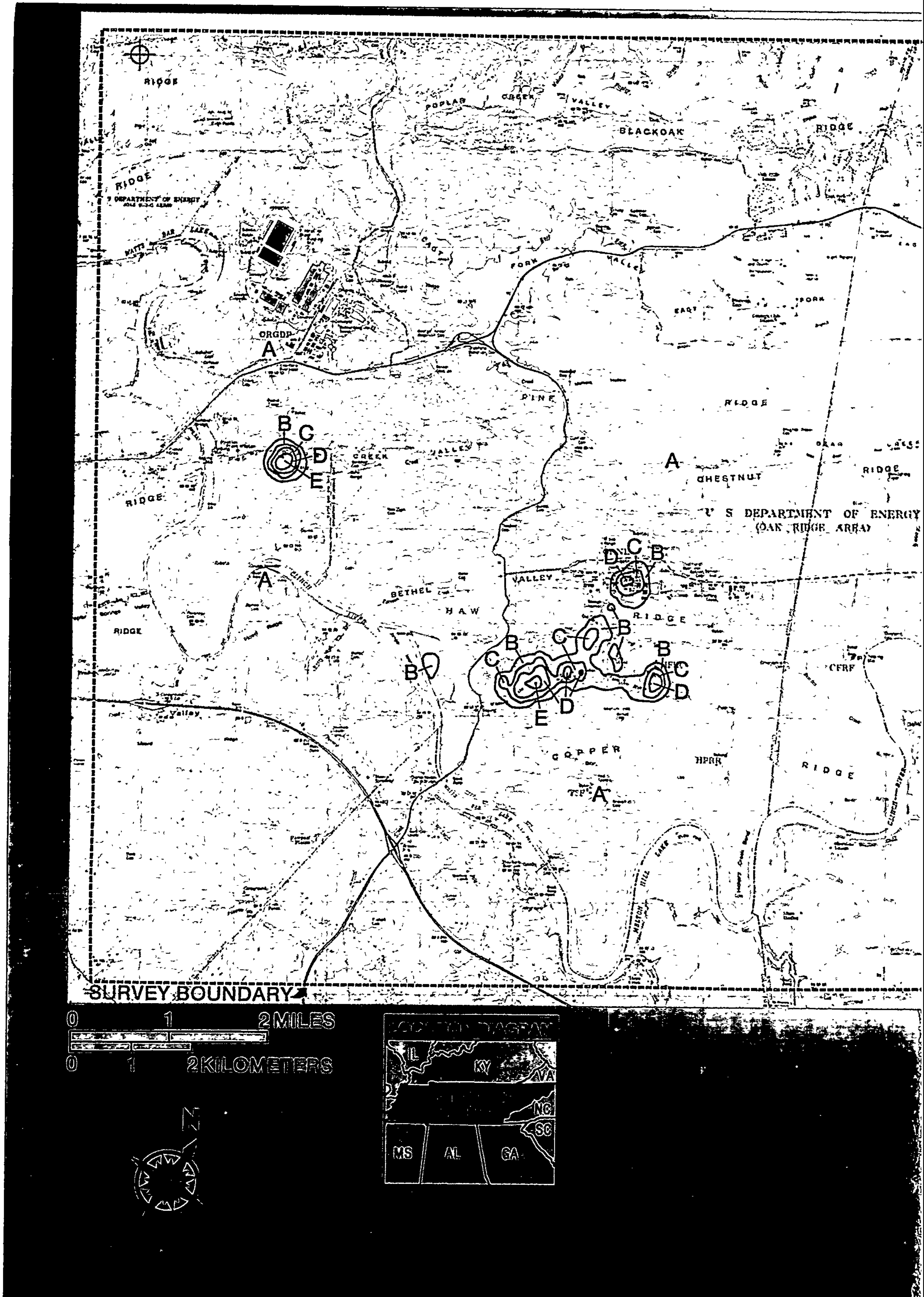
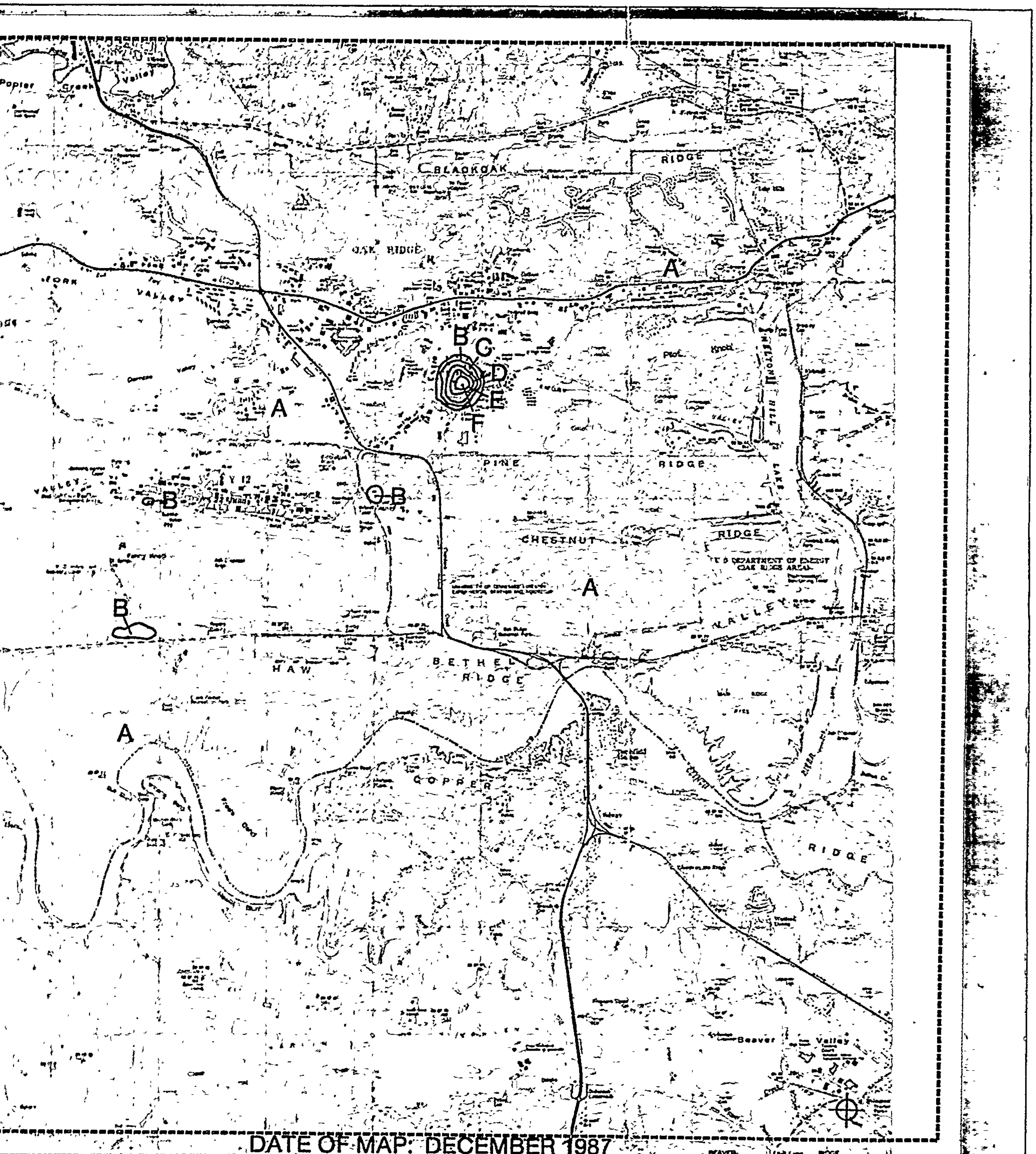


FIGURE 6. *PHOTOPEAK COUNT RAT*



*Summed counts from 1,046 to 1,466 keV

**At flight altitude of 91m (300 ft) eight 2" × 4" × 16" NaI(Tl) gamma detectors

COBALT-60 CONVERSION SCALE* (PHOTOPEAKS AT 1,173 AND 1,332 keV)

LETTER LABEL	COUNTS PER SECOND**
A	< 150
B	150 - 460
C	460 - 1,200
D	1,200 - 3,700
E	3,700 - 12,000
F	12,000 - 30,000

CONTOUR MAP FOR COBALT-60

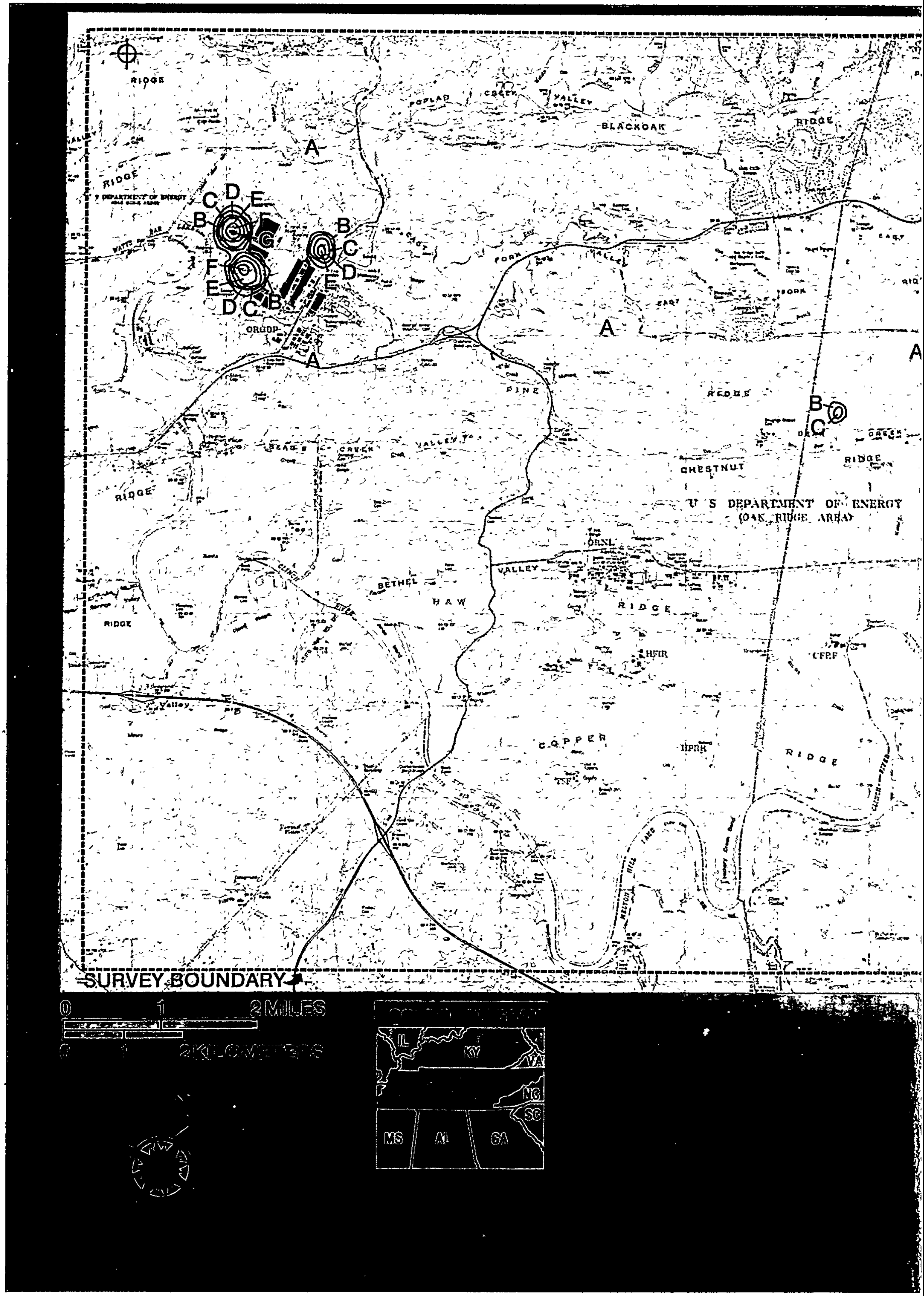
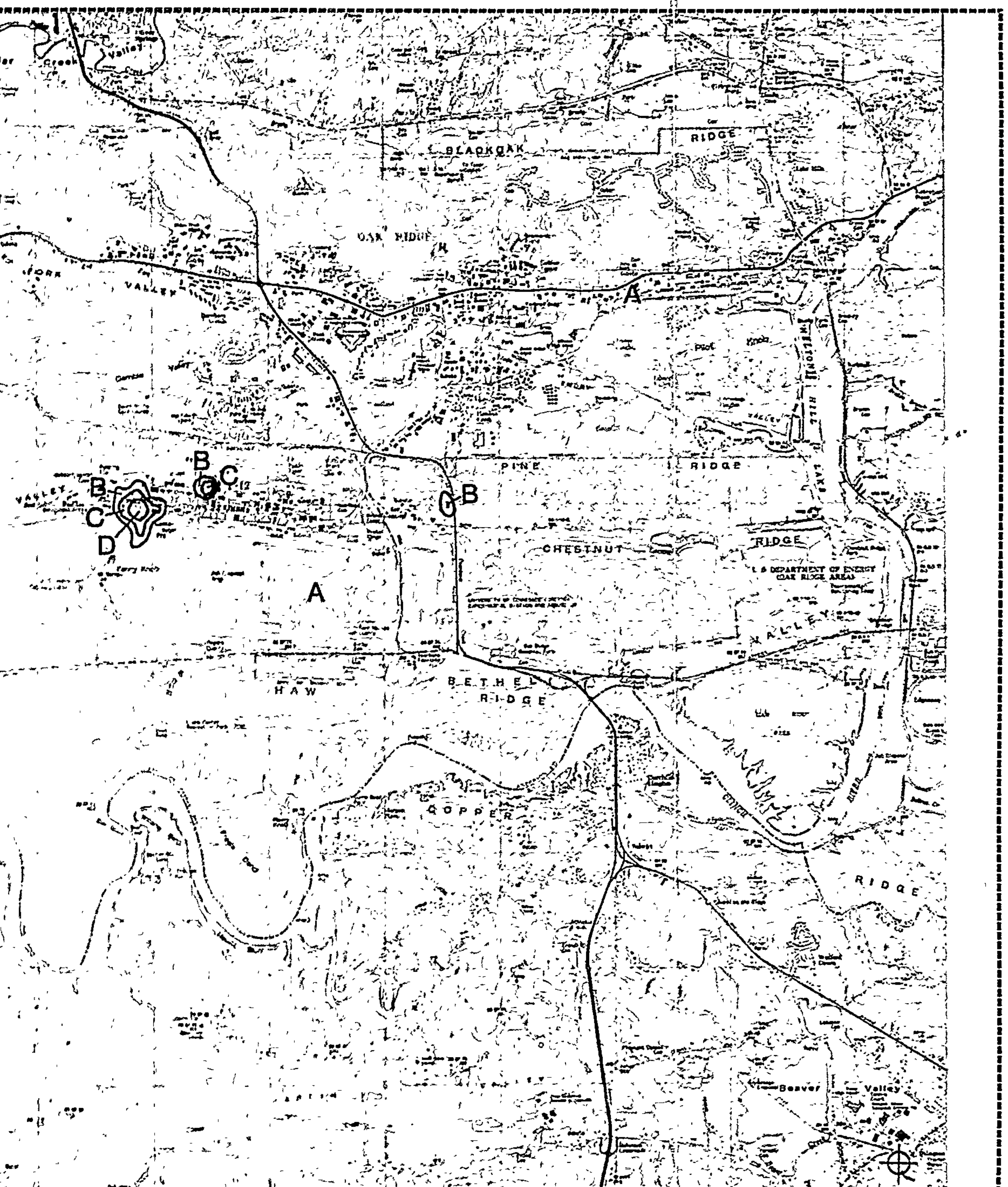


FIGURE 7. *PHOTOPEAK COUNT RATE CON*



DATE OF MAP: DECEMBER 1987

*Summed counts from 902 to 1,106 keV

**At flight altitude of 91m (300 ft) eight 2" × 4" × 16" NaI(Tl) gamma detectors

LETTER LABEL	COUNTS PER SECOND**
A	< 70
B	70 – 170
C	170 – 450
D	450 – 1,400
E	1,400 – 4,000
F	4,000 – 10,000
G	10,000 – 28,000

TOUR MAP FOR PROTACTINIUM-234m

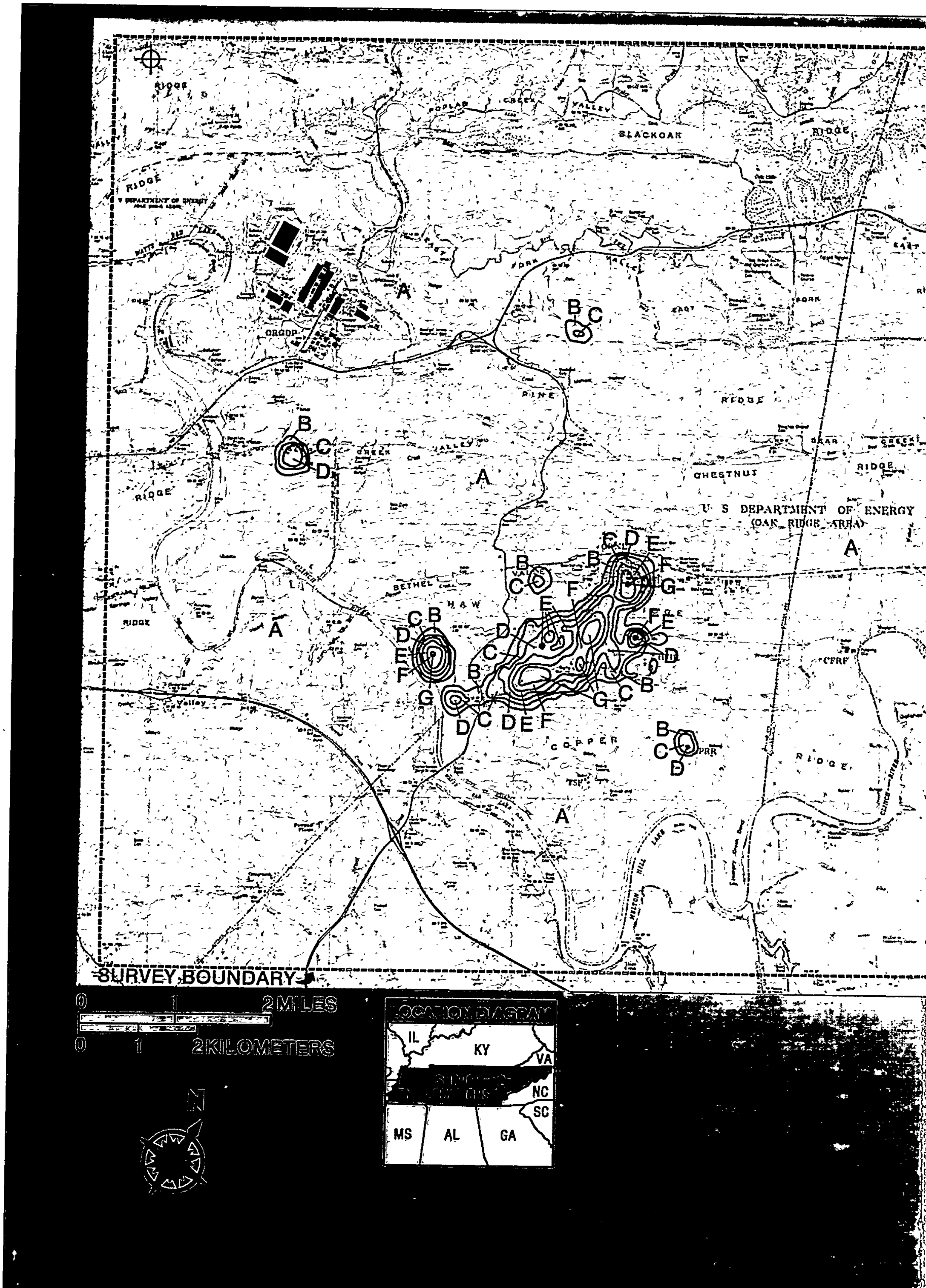
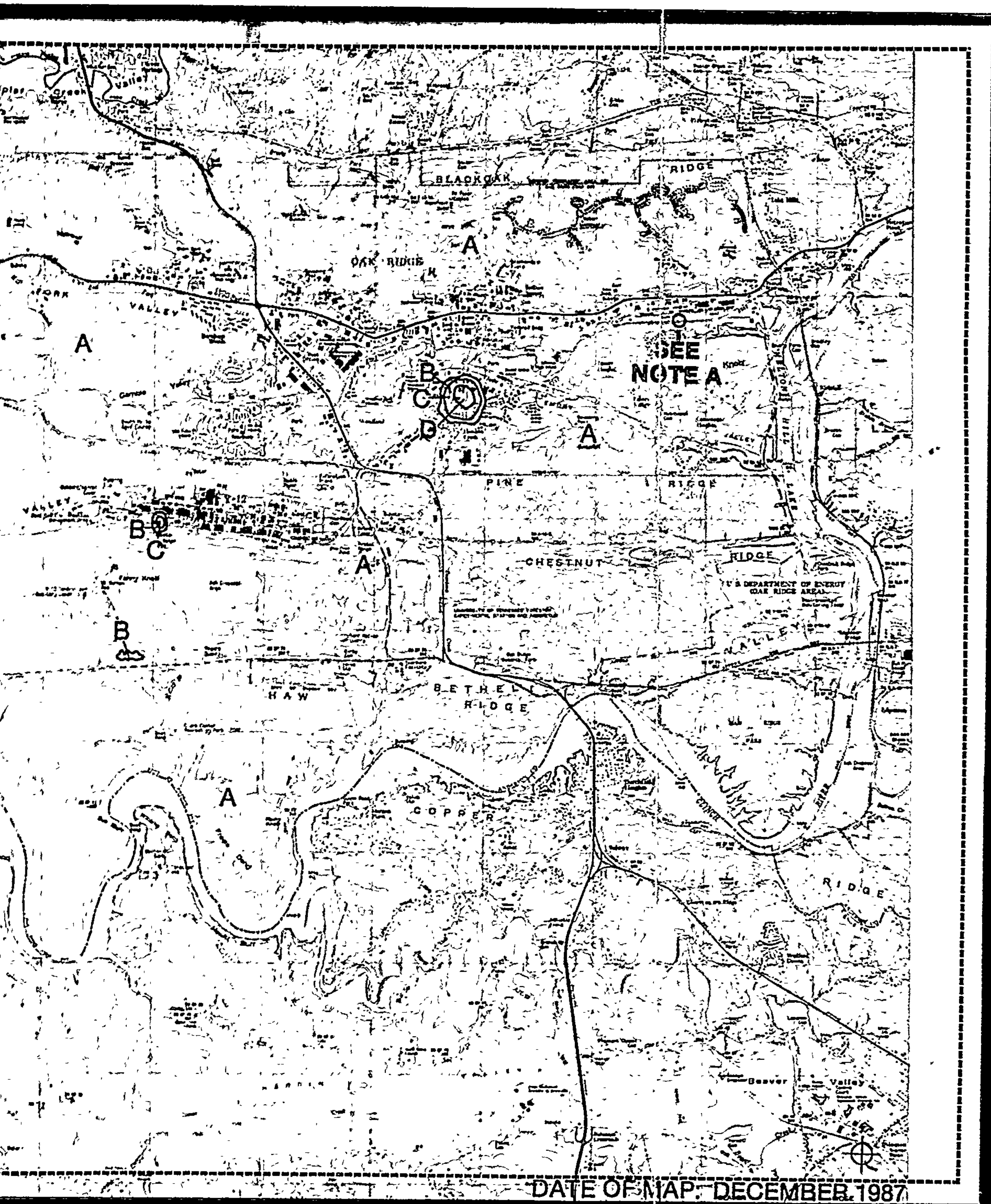


FIGURE 8. *PHOTOPEAK COUNT RATE*



NOTE A

Cesium-137 was detected at this location during the special flight over the railroad track. This location was not detected during the primary survey.

*Summed counts from 590 to 734 keV

**At flight altitude of 91m (300 ft) eight 2″ × 4″ × 16″ NaI(Tl) gamma detectors

CESIUM-137 CONVERSION SCALE (PHOTOPEAK AT 662 keV)

LETTER LABEL	COUNTS PER SECOND**
A	< 80
B	80 - 220
C	220 - 660
D	660 - 2,000
E	2,000 - 5,500
F	5,500 - 20,000
G	20,000 - 66,000

CONTOUR MAP FOR CESIUM-137

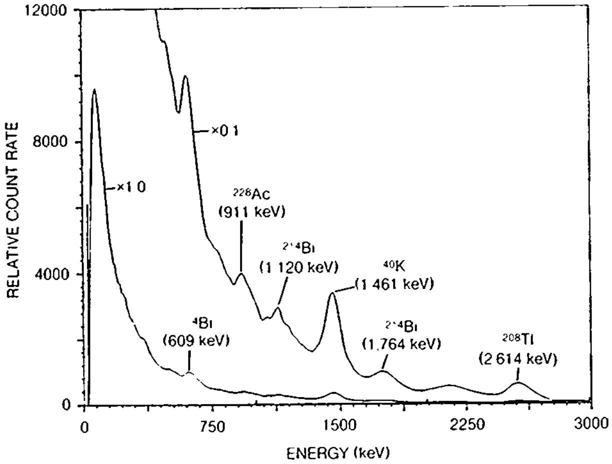


FIGURE 9. ***TYPICAL BACKGROUND SPECTRUM FOR THE OAK RIDGE AREA***

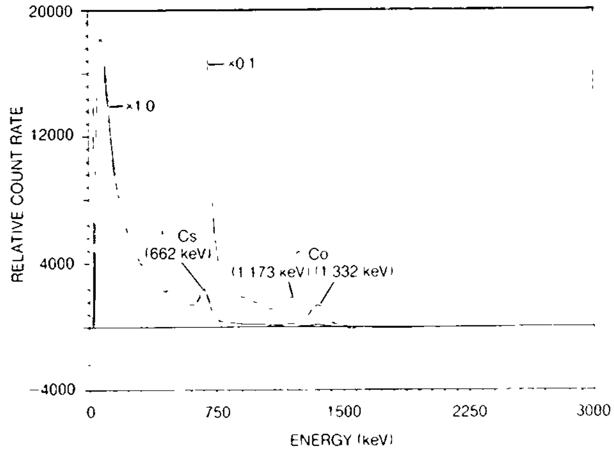


FIGURE 10. ***NET SPECTRUM FROM REGION OF INTEREST 1***

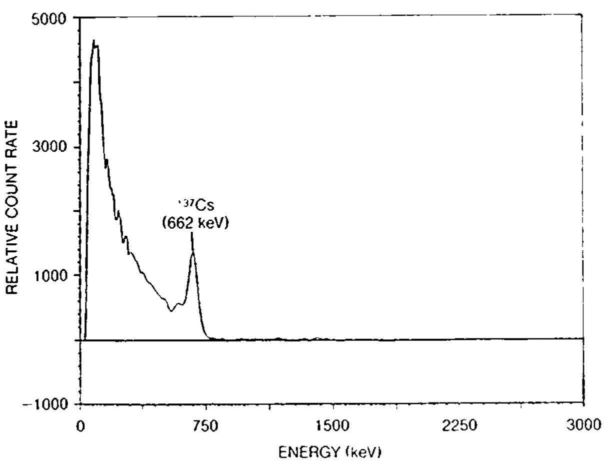


FIGURE 11. ***NET SPECTRUM FROM REGION OF INTEREST 2***

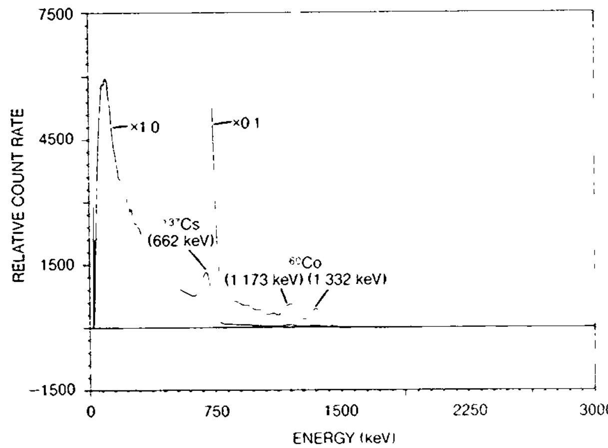


FIGURE 12. ***NET SPECTRUM FROM REGION OF INTEREST 3***

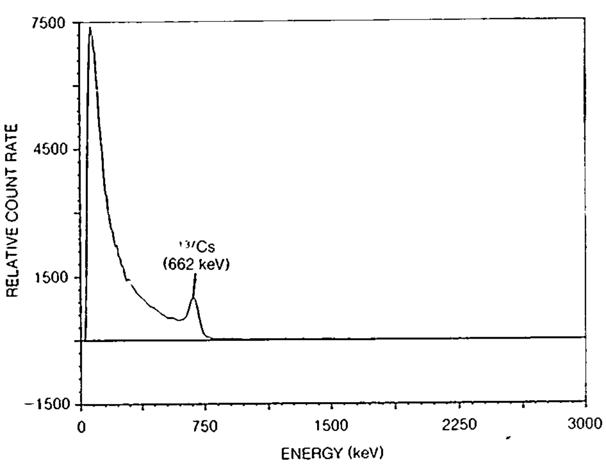


FIGURE 13. ***NET SPECTRUM FROM REGION OF INTEREST 4***

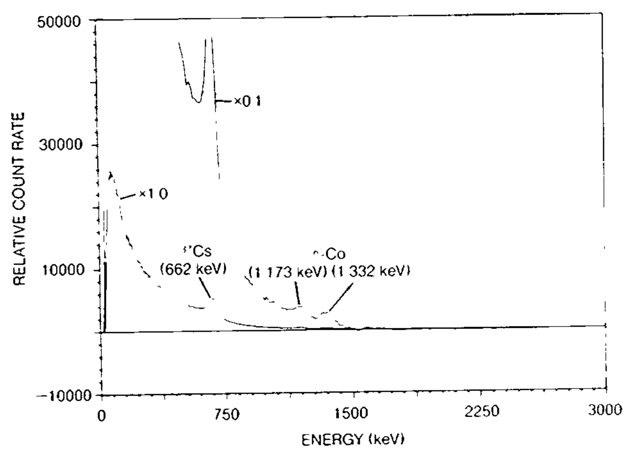


FIGURE 14. ***NET SPECTRUM FROM REGION OF INTEREST 5***

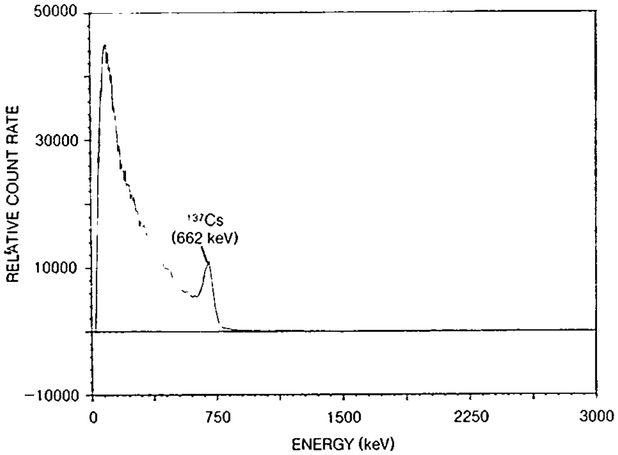


FIGURE 15. ***NET SPECTRUM FROM REGION OF INTEREST 6***

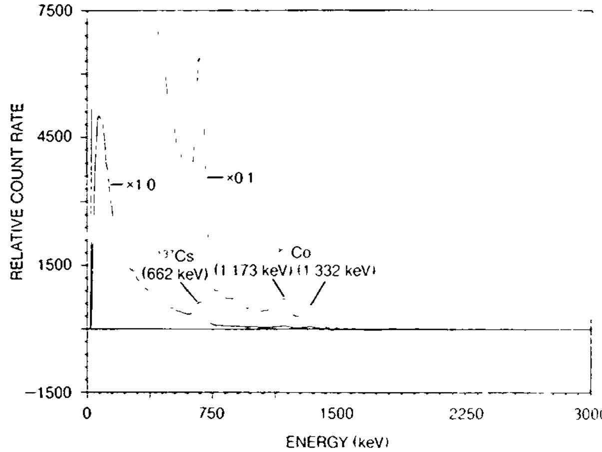


FIGURE 16. ***NET SPECTRUM FROM REGION OF INTEREST 7***

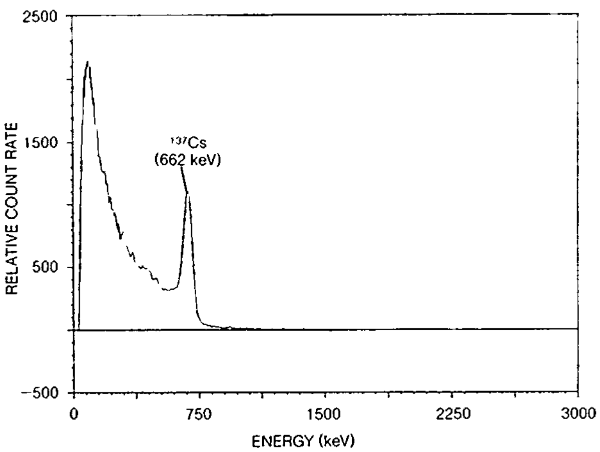


FIGURE 17. NET SPECTRUM FROM REGION OF INTEREST 8

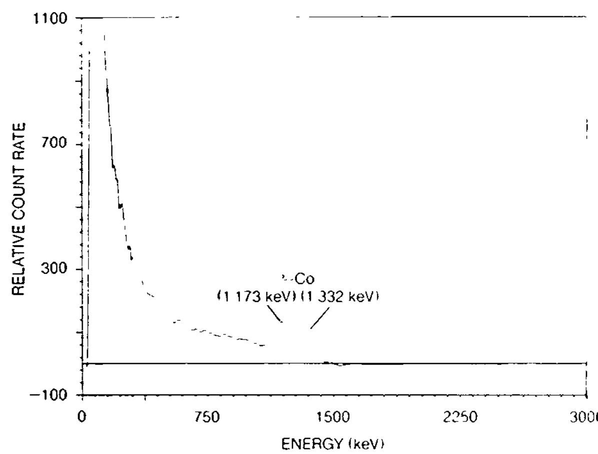


FIGURE 18. ***NET SPECTRUM FROM REGION OF INTEREST 9***

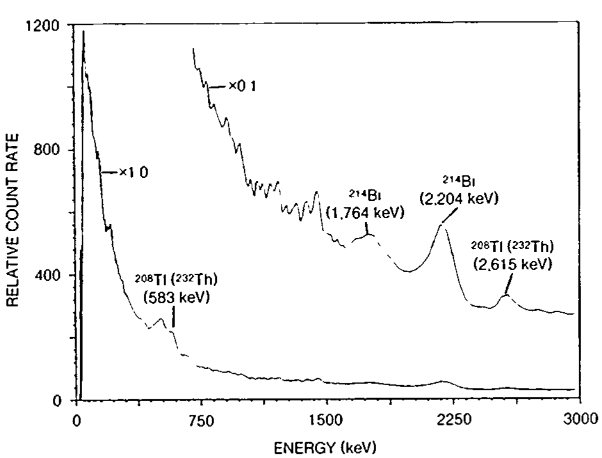


FIGURE 19. ***SPECTRUM FROM REGION OF INTEREST 10***

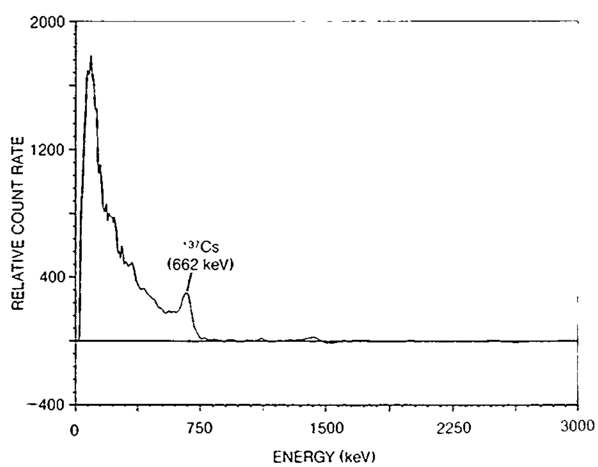


FIGURE 20. ***NET SPECTRUM FROM REGION OF INTEREST 11***

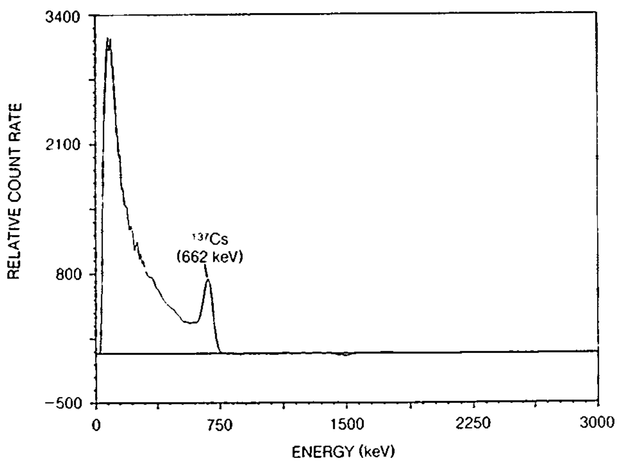


FIGURE 21. ***NET SPECTRUM FROM REGION OF INTEREST 12***

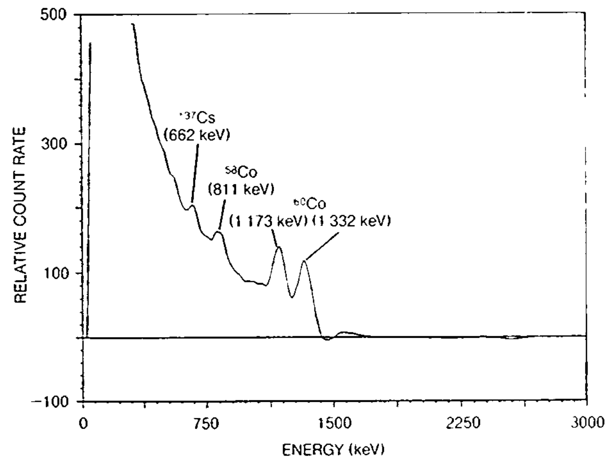


FIGURE 22. ***NET SPECTRUM FROM REGION OF INTEREST 13***

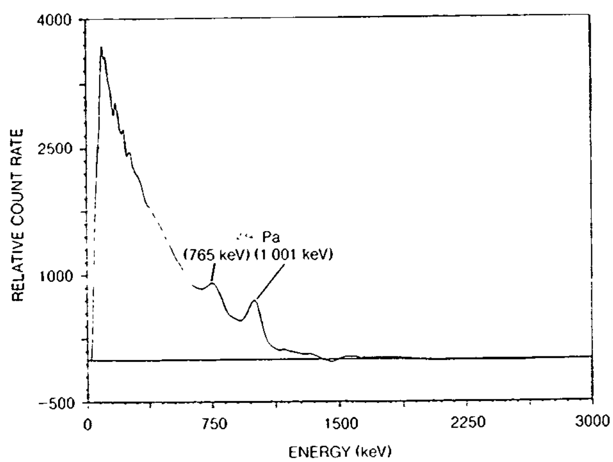


FIGURE 23. NET SPECTRUM FROM REGION OF INTEREST 14

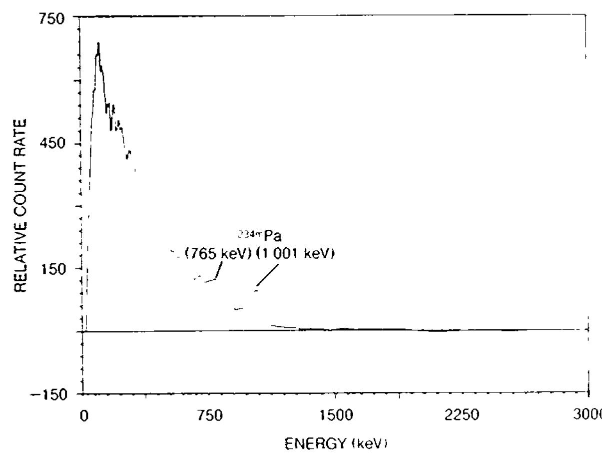


FIGURE 24. ***NET SPECTRUM FROM REGION OF INTEREST 15***

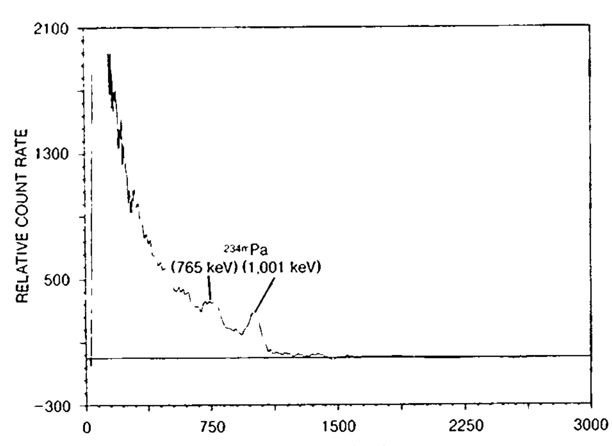


FIGURE 25. ***NET SPECTRUM FROM REGION OF INTEREST 16***

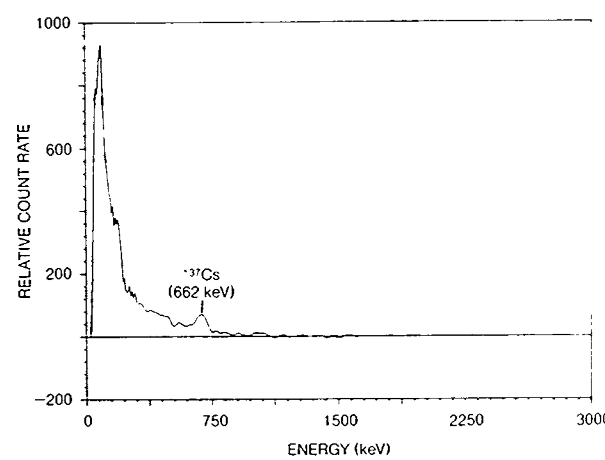


FIGURE 26. ***NET SPECTRUM FROM REGION OF INTEREST 17***

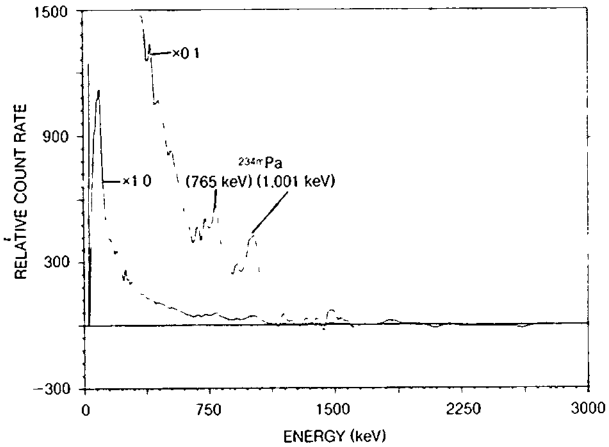


FIGURE 27. *NET SPECTRUM FROM REGION OF INTEREST 18*

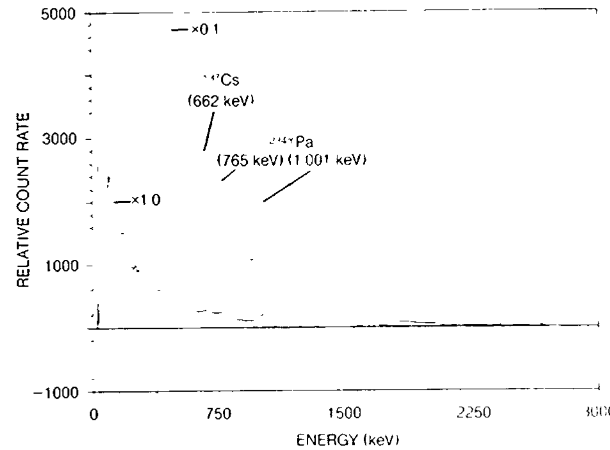


FIGURE 28. *NET SPECTRUM FROM REGION OF INTEREST 19*

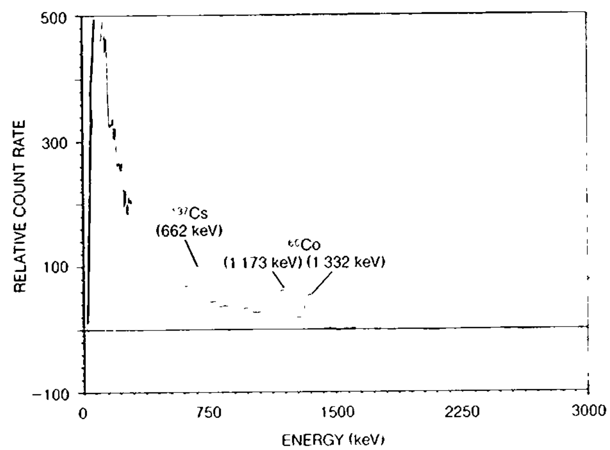


FIGURE 29. *NET SPECTRUM FROM REGION OF INTEREST 20*

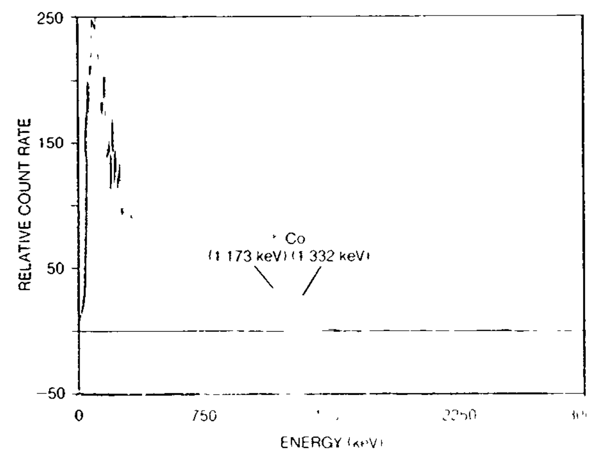


FIGURE 30. *NET SPECTRUM FROM REGION OF INTEREST 21*

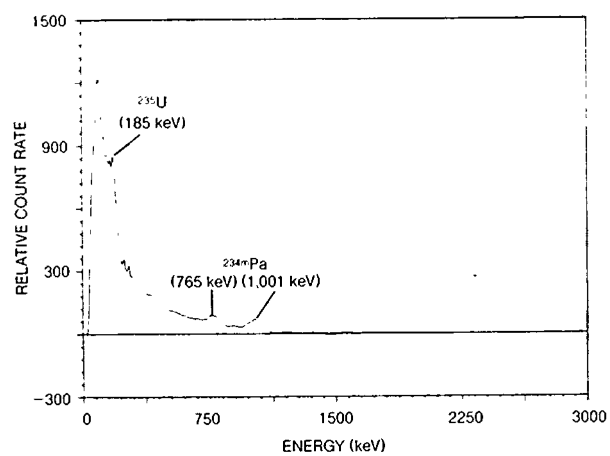


FIGURE 31. *NET SPECTRUM FROM REGION OF INTEREST 22*

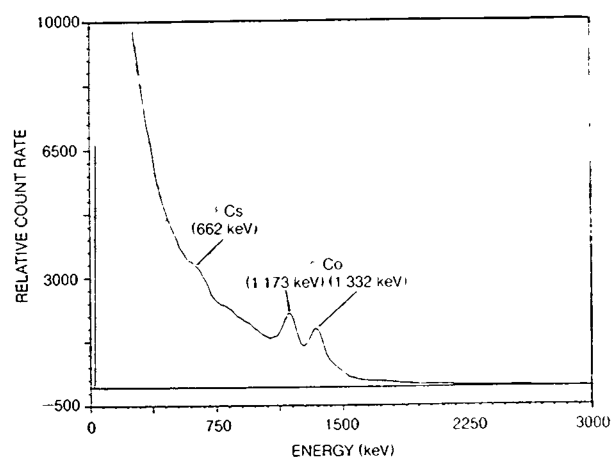


FIGURE 32. *NET SPECTRUM FROM REGION OF INTEREST 23*

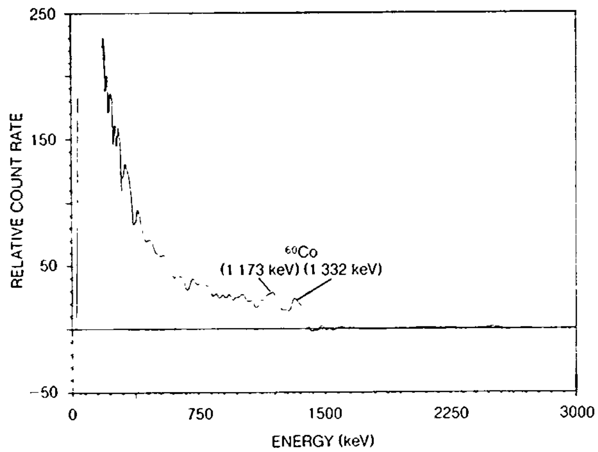


FIGURE 33. ***NET SPECTRUM FROM REGION OF INTEREST 24***

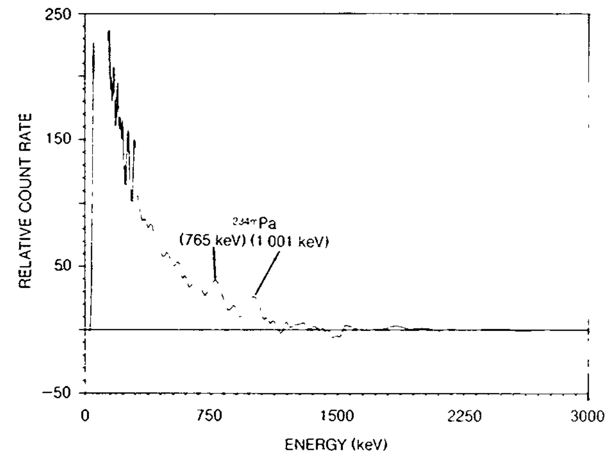


FIGURE 34. ***NET SPECTRUM FROM REGION OF INTEREST 25***

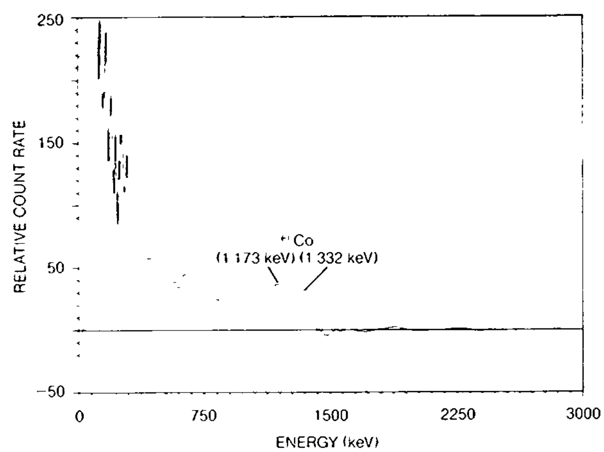


FIGURE 35. NET SPECTRUM FROM REGION OF INTEREST 26

6.5 Ground-Based Measurements

In situ gamma ionization chamber and soil sample measurements were obtained from four benchmark sites outside of the Oak Ridge Reservation to support the integrity of the aerial survey. The exposure rates from the inferred aerial and ground-based measurements[12] are listed in Table 2. The exposure rates inferred from the aerial survey were found to be in good agreement with the ground-based measurements. The slightly lower exposure rate measured at Site 3 is indicative of the adjacent wetland areas of Poplar Creek.

The results of the radionuclide assay for the soil samples are given in Table 3. The concentrations of U-238 and Th-232 were found to be in good agreement with those typically found in the environment; however, the K-40 concentrations for Sites 1, 3, and 4 were slightly low. The Cs-137 concentrations measured in the Oak Ridge area were found to be typical of those measured in the eastern United States.[7]

Table 2. Exposure Rates from Aerial and Ground-Based Measurements			
	1-Meter Gamma Exposure Rate (μR/h)		
Site No.	Aerial Survey	Soil Analysis[1]	Ion Chamber[2]
1	8.7 ± 1.5	8.3 ± 0.9	8.2 ± 1.3
2	9.5 ± 1.4	10.0 ± 1.0	8.9 ± 0.5
3	6.8 ± 1.0	10.0 ± 0.6	9.4 ± 0.5
4	7.9 ± 1.2	9.1 ± 0.7	8.5 ± 0.5

[1] Calculation includes cosmic ray contribution of 3.8 μR/h and a moisture correction of the form 1/(1+m)

[2] Reuter Stokes Model #RSS-111, Serial #G003.

Table 3. Radionuclide Assay of Soil Samples					
Site No.	Moisture %	U-238 ppm	Th-232 ppm	Cs-137 pCi/g	K-40 pCi/g
1	17 ± 2	3.8 ± 0.5	8 ± 1	0.5 ± 0.1	4 ± 1
2	19 ± 3	3.5 ± 0.5	10 ± 1	0.4 ± 0.2	13 ± 2
3	19.5 ± 0.8	4.0 ± 0.5	11.3 ± 0.5	0.6 ± 0.1	7.7 ± 0.2
4	20 ± 2	4.1 ± 0.4	9.3 ± 0.5	0.35 ± 0.06	5 ± 1

6.6 Results and Discussion of Special Flyovers

At the request of the DOE, two special flyovers were conducted in conjunction with the large-scale aerial survey. The first request was to survey an area in south Knoxville where several scrap metal storage yards are located. The storage yards were previously used to store radioactive scrap metals from DOE operations at the Oak Ridge site. The second request was to survey the railroad tracks leading north from the Y-12 Plant through the city of Oak Ridge. In the early 1960s, the Oak Ridge National Laboratory was the regional burial ground for low-level radioactive waste. The waste was routinely shipped by train and offloaded for transport to ORNL.

On September 27, a 5.2-square-kilometer (2-square-mile) area in south Knoxville was surveyed at an altitude of 38 meters (125 feet) using a grid pattern with flight lines 61 meters (200 feet) apart. The low altitude was chosen to maximize the AMS sensitivity for the low specific activity of the radioactive materials. The terrestrial gamma exposure rate contour map generated from the survey data was overlaid on a USGS topographic map (Knoxville Quadrangle 147 NW) and is presented in Figure 36. The exposure rates, which were found to vary from 5 to 14 μR/h, are reported in units of μR/h at 1 meter AGL inferred from the aerial data. No anomalous radiation levels attributed to man-made radionuclides were detected by the AMS in the survey area.

On September 28, an 8-kilometer (5-mile) length of railroad tracks, beginning at the Y-12 Plant, was surveyed by flying four passes over the tracks. The survey was conducted at an altitude of 38 meters (125 feet) to maximize the AMS sensitivity for point sources of Cs-137. Two areas

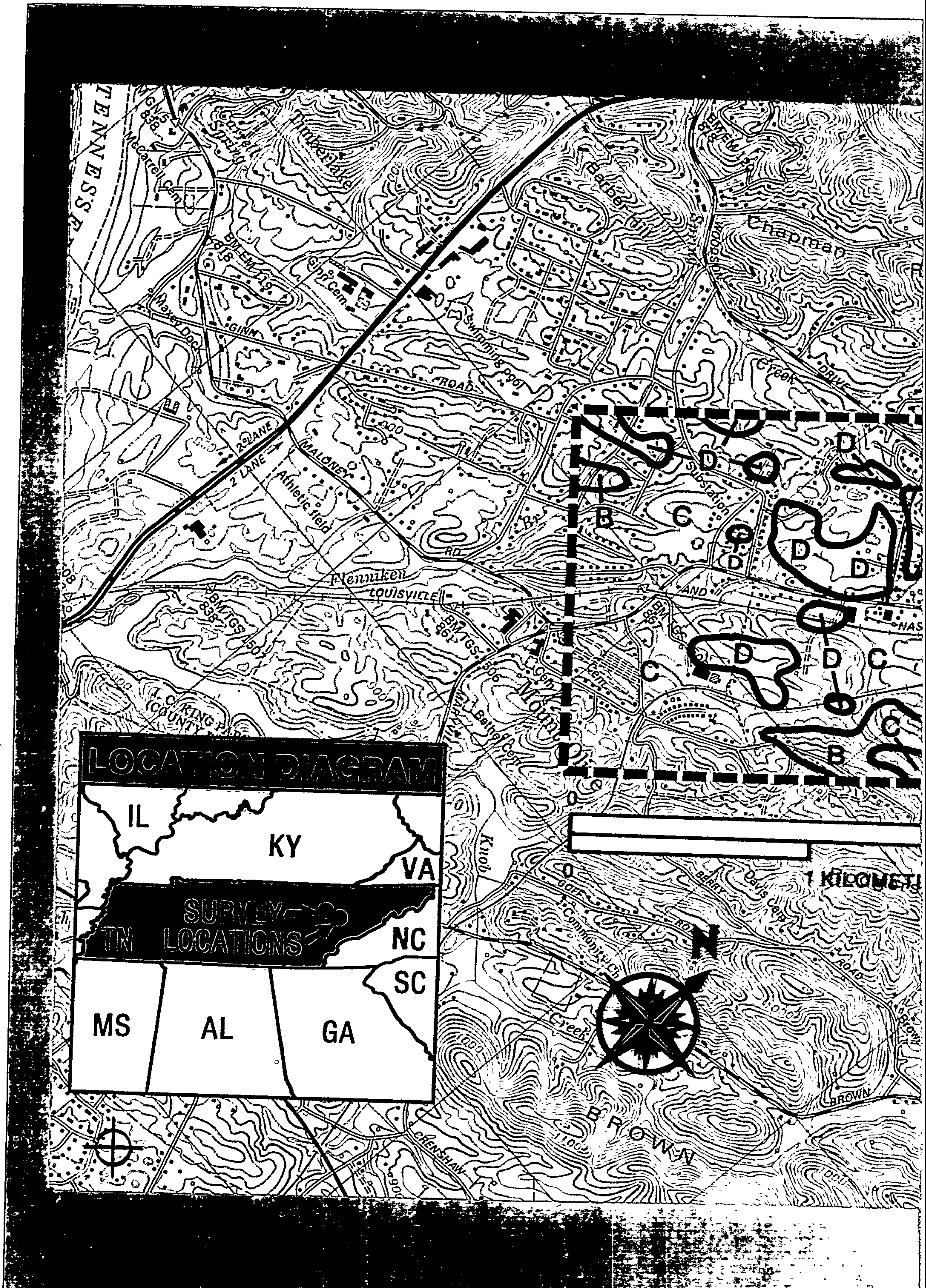
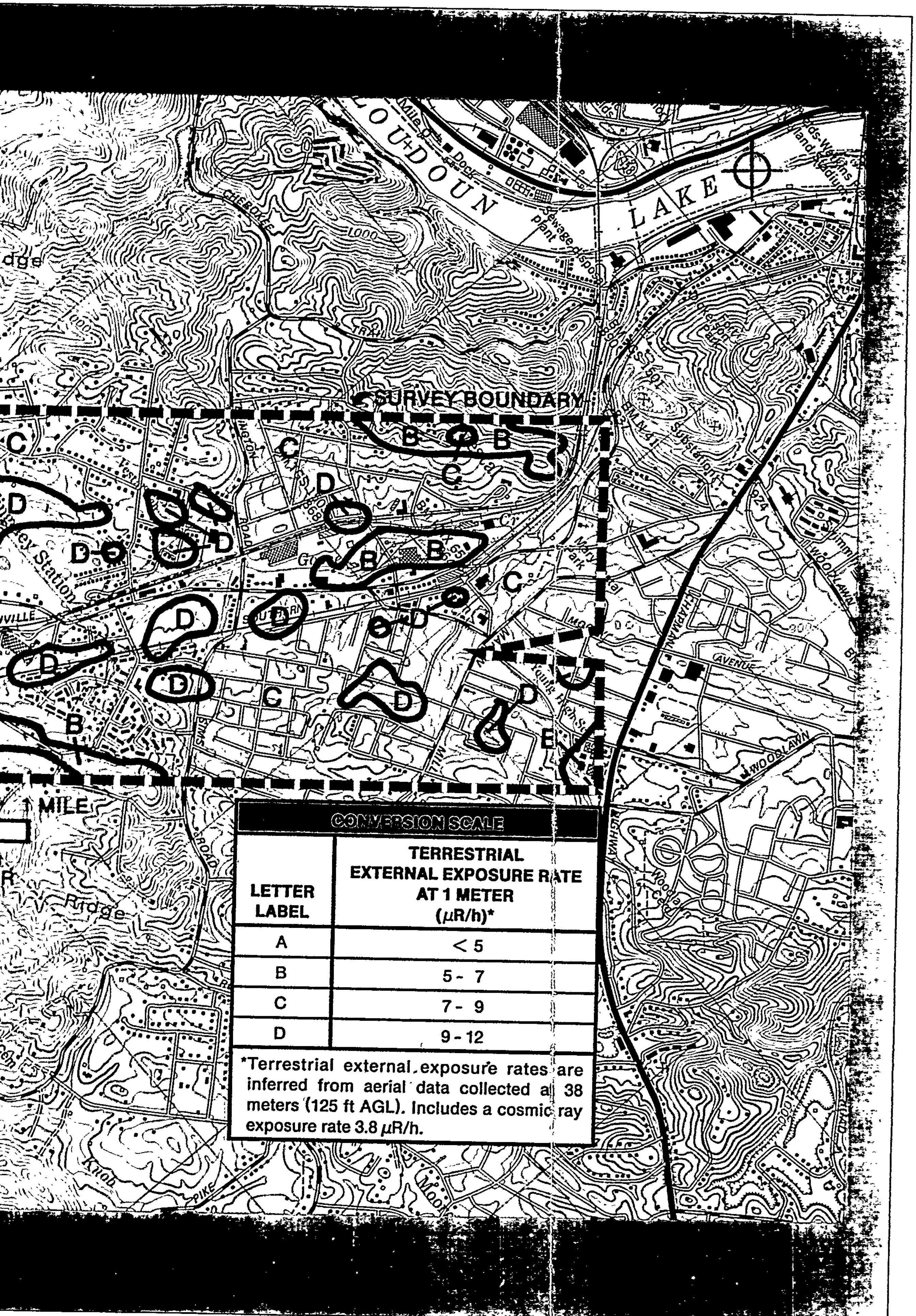


FIGURE 36. *TERRESTRIAL GAMMA EXPOSURE RATE CON*
SOUTH KNOXVILLE, TENNESSEE



LETTER LABEL	TERRESTRIAL EXTERNAL EXPOSURE RATE AT 1 METER (μR/h)*
A	< 5
B	5 - 7
C	7 - 9
D	9 - 12

*Terrestrial external exposure rates are inferred from aerial data collected at 38 meters (125 ft AGL). Includes a cosmic ray exposure rate 3.8 μR/h.

TOUR MAP FOR THE SCRAP METAL STORAGE YARDS IN were found to exhibit anomalous radiation levels attributed to Cs-137 activity. One area was detected in the large-scale area survey (denoted ROI 23, Figure 32). It is the site of an industrial facility located adjacent to the railroad tracks near Emory Road in the city of Oak Ridge. The second area is located on the railroad tracks approximately two-thirds mile west of the intersection with Melton Lake Drive. The location of this area is denoted as ROI B on the MMGC contour map (Figure 5) and highlighted in Note A on the Cs-137 contour map (Figure 8). The net gamma spectrum from this area, which is presented in Figure 37, shows a dominate photopeak attributed to Cs-137.

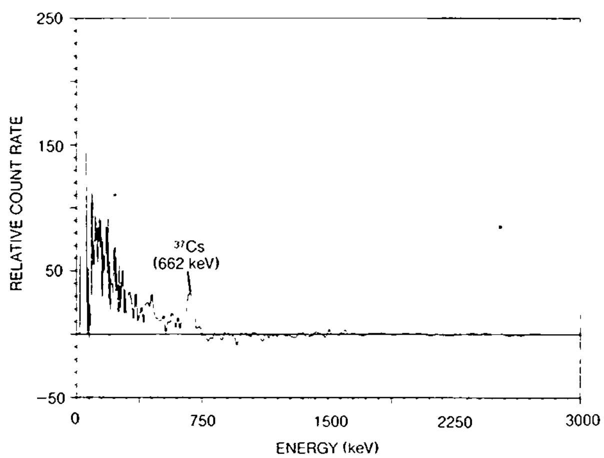


FIGURE 37. ***NET SPECTRUM FROM REGION OF INTEREST B***

7.0 COMPARISON OF 1980 AND 1989 AERIAL SURVEYS

In the following section, a comparison of the radiation data from the 1980 and 1989 aerial surveys is presented. Several noteworthy changes in the radiological status of the Oak Ridge site and nearby surrounding area were observed.

In the present survey, four anomalous radiation areas were identified outside of the DOE boundary of the Oak Ridge Reservation. The first site (ROI 23) is a commercial decontamination and metals processing facility located in the city of Oak Ridge, north of the railroad tracks in the industrial park off of Emory Road. The radioisotopes identified at the site from the gamma spectrum (Figure 32) are Co-60 and Cs-137.

Two anomalous radiation areas were identified south of the city of Oak Ridge. Located approximately one-eighth of a mile east of Scarborough Road where the railroad tracks enter the Y-12 Plant is ROI 21 (Figure 30) which was identified to contain Co-60. ROI 21, located in the Union Valley Industrial Park, was formerly a commercial facility for the storage of contaminated equipment. The facility was decommissioned in 1990. ROI 25 (Figure 34), located on South Illinois Avenue approximately one-quarter mile north of the intersection with Union Valley Road, also exhibited anomalous radiation levels which are attributed to Pa-234m. ROI 25 is a commercial facility which rolls depleted uranium to produce accelerator shielding.

ROI 13, located on Bear Creek Road, is a commercial, low-level radioactive waste processing, compaction, and incineration facility. The gamma spectrum from ROI 13 (Figure 22) shows photopeaks from Co-60 and Cs-137 as well as a photopeak at 811 keV, indicative of cobalt-58 (Co-58).

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An area of anomalous radiation on the ORR, not detected in the 1980 survey, is ROI 20. ROI 20 is located off the ORR approximately one mile south of the Y-12 Plant at the intersection of Bethel Valley Road and Mount Vernon Road. ROI 20 is a sludge application area for the city of Oak Ridge. During late 1983 and early 1984, sludge contaminated with Cs-137 and Co-60 from the facility at ROI 23 was unknowingly deposited at that site. The gamma spectrum from ROI 20 (Figure 29) shows evidence for both Cs-137 and Co-60 activity.

Over the past decade, several noteworthy changes have also occurred in the status of the man-made radioactivity within the DOE boundary on the Oak Ridge Reservation. Several radiation areas which were identified in the 1980 survey were not detected in the present survey. The anomalous radiation area near Freels Bend, detected in the 1980 survey, was from the Variable Dose Rate Irradiation Facility (VDRIF) when the Co-60 sources were in their irradiation position. In August 1984, the facility was shut down. The sources still remain in their shields in the VDRIF but were not detectable by the AMS.

The White Oak Creek Floodplain (ROIs 1-12), which was found to exhibit Co-60 and Cs-137 in the 1980 survey, was also detected in the present survey and showed only subtle changes. One significant change was at the Tower Shielding Facility. The Tower Shielding Facility, which exhibited Co-60 activity in 1980, showed no anomalous radiation levels in the present survey.

A comparison of the Pa-234m contour plots from the 1980 and 1989 surveys shows that the location of the uranium hexafluoride cylinder storage yards at the K-25 Site has changed in the last decade. Two sites, located south of ROI 16, were found to contain Pa-234m in the 1980 survey. The present survey shows no indication of Pa-234m at these sites. Due north of ROI 14, however, is ROI 15 (Figure 24) which shows evidence for Pa-234m activity not detected in the 1980 survey.

Due south of the K-25 Site is the K-25 Contaminated Metal Scrap Yard, ROI 24. The gamma spectrum from ROI 24 (Figure 33) shows evidence for Co-60 activity near the plant. The Co-60 is from heat exchangers that came from ORNL.

The present survey revealed for ROI 22 a prominent 185 keV photopeak indicative of uranium-235 (U-235). The photopeak was not observed during the 1980 survey.

Located due south of the Y-12 Plant on Chestnut Ridge is ROI 10. ROI 10 appears as a negative value on the MMGC contour map (Figure 5). Due to the nature of the MMGC algorithm (Equation 2), a negative contour is typically indicative of enhanced gamma activity in the energy window from 1,394 keV to 3,026 kev. In fact, the gamma spectrum from ROI 10 (Figure 19) shows evidence for thallium-208 (Tl-208) and bismuth-214 (Bi-214), daughter products of Th-232 and U-238, respectively.

However, extensive ground measurements[6] of the Chestnut Ridge area by Oak Ridge personnel showed no evidence for anomalous radiation levels. Further investigations by Oak Ridge personnel revealed that during the overflight of Chestnut Ridge on September 20, a total of 63 sludge containers, each 30 square feet in area, were being stored on the ridge. The containers were subsequently shipped on September 23 to the Y-12 Plant (Building 9720-9) for storage. A review of the analysis of the individual containers yielded concentrations ranging from less than 1 to 300 ppm Th-232, with most of the containers less than 30 ppm, and 1 to 18,000 ppm U-238, with about half of the containers less than 100 ppm. Exposure rate measurements on individual containers yielded values ranging from 3 to 58 μR/h. It should be noted that the negative area represented by ROI 10 is considerably larger than the aggregate sum of the areas for the individual containers. This is a result of the spatial resolution of the aerial measuring system which, for the present survey altitude, yields a detection footprint with a 500-foot diameter.

8.0 SUMMARY

A radiological survey of the Oak Ridge Reservation and surrounding area was conducted from September 12-29, 1989. The survey was conducted at 91 meters (300 feet) AGL over a 440-square-kilometer (170-square-mile) area as defined by the TVA Map S-16A. The terrestrial exposure rates at 1 meter AGL were found to vary from 5 to 14 μR/h. The man-made radionuclides, Co-60, Pa-234m, and Cs-137, were detected at several of the Oak Ridge complexes. In addition, four anomalous radiation areas were detected outside the DOE boundary of the Oak Ridge Reservation. Three of the sites are located in or near an industrial park south of the city of Oak Ridge, and the fourth is at the west end of the Oak Ridge Reservation.

Two special flyovers (at 125 feet AGL) were conducted at the request of the DOE. The first flyover was conducted over a 2-square-mile area in south Knoxville which was previously used for storage of contaminated scrap metals from the DOE operations. The aerial survey revealed no evidence for anomalous radiation levels. The second flyover was conducted along the railroad tracks leading from the Y-12 Plant through the city of Oak Ridge. The railroad track survey revealed one additional anomalous radiation area which was attributed to Cs-137.

APPENDIX A
SURVEY PARAMETERS

Survey Site:	Oak Ridge Reservation Oak Ridge, Tennessee
Survey Coverage:	440 sq km (170 sq mi)
Survey Date:	September 12-29, 1989
Survey Altitude:	91 m (300 ft)
Aircraft Speed:	36 m/s (70 knots)
Line Spacing:	152 m (500 ft)
Line Direction:	East-West
Detector Array:	Eight 5.1-cm $\times$ 10.2-cm $\times$ 40.6-cm (2-in $\times$ 4-in $\times$ 16-in) NaI(Tℓ) detectors
Acquisition System:	REDAR IV
Conversion Factor:	693 cts/sec/μR/h at 91 m
Air Attenuation Coefficient:	0.0019/ft
Aircraft:	MBB BO-105 Helicopter
Survey Crew:	R. Maurer, L. Ruff, E. Smith, J. Holtzclaw, A. Van Order, L. Watson, L. Komich, S. Bartley, M. Witt, R. Mohr

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